THE EFFECT OF RAPID MAXILLARY EXPANSION ON NASAL AIRWAY RESISTANCE, CRANIOFACIAL MORPHOLOGY AND HEAD POSTURE

James Peter McDonald

Thesis presented for the degree of

Doctor of Philosophy

of the University of Edinburgh

1994

ABSTRACT

The adequacy of the nasopharyngeal airway has been found to be related to craniofacial development in that obstruction of the airway by excess adenoidal tissue, nasal septal deformity or other abnormal morphology in the area is associated with characteristic changes in craniofacial morphology.

The present study investigated the differences in nasal airway resistance, (to include the laminar and turbulent components), craniofacial morphology and head posture between a control group and an anomaly group exhibiting full transverse cusp bilateral crossbites and further investigated the changes that occurred in these parameters when the anomaly group was treated using rapid maxillary expansion.

The method error of both the measurement system for cephalometry and nasal airway resistance was tested by duplicate determinations and subsequent statistical analysis, as was the method error of the operator. All the variables in the study were found to be reproducible without systematic error and with a very small method error.

The results of the rhinomanometric readings showed that there were significant differences in nasal airway resistance between the control and anomaly samples, and that significant changes in nasal airway resistance occurred in the anomaly subjects when they were treated with rapid maxillary expansion. However when head posture was investigated, no significant differences in craniocervical angulation were discovered between the control and anomaly samples, or between the anomaly sample before and after treatment.

The craniofacial morphology values, measured using lateral cephalometric radiographs and postero-anterior radiographs, were found to exhibit some significant differences between the control and anomaly subjects, and to exhibit some significant changes where the anomaly sample was treated with rapid maxillary expansion.

TABLE OF CONTENTS

Abstract i

Contents ii

List of Tables iv

List of Figures ix

Acknowledgements xii

Declaration xiii

1. LITERATURE REVIEW

1.1 Rhinomanometry 1

1.2 Head posture, craniofacial morphology and nasal airflow 8

1.3 Rapid maxillary expansion 14

1.4 Rapid maxillary expansion and nasal airway resistance 23

1.5 Summary 25

2. AIMS AND OBJECTIVES OF STUDY 27

3. CLINICAL MATERIAL AND METHODS

3.1 Clinical subjects 31

3.2 Rapid maxillary expansion 37

3.3 Measurement Procedures 46

3.4 Measurements - Definitions and Calculations 59

3.5 Statistical Procedures 60

4. METHOD ERROR

4.1 Rhinomanometric method error 79

4.2 Postero-anterior radiographic method error 82

4.3 Head posture method error 85

4.4 Cephalometric variables method error 89

5. **RESULTS**

5.1 Differences between the Control Sample and the Anomaly Sample before Treatment 94

5.2 Changes in the Anomaly Sample with Treatment 147

6. **DISCUSSION** 175

7. **CONCLUSION** 196

8. **GLOSSARY OF EQUIPMENT USED** 198

9. **APPENDIX** 202

10. **REFERENCES** 204

LIST OF TABLES

Table	Title	Page
1	Nasal airflow characteristics in a normal sample	6
2	Normal values for nasal airway resistance in children	7
3	Age distributions in each group	32
4	Cephalometric reference points used in the study	61
5	Radiographic cephalometric measurements	69
6	Reference lines used in study	73
7	Transverse point definitions	75
8	Transverse linear measurements	77
9	Method errors in nasal airway resistance	80
10	Method errors in nasal airway resistance compared with a previous study	81
11	Method errors - postero-anterior variables	84
12	Method errors - postural angles	87
13	Method errors - postural angles in previous studies	88
14	Method errors - cephalometric variables	90
15	Comparison rhinomanometric variables between males and females in the control sample	96
16	Comparison rhinomanometric variables between the laminar and turbulent components of NAR in males and females in the control sample	97

Table	Title	Page
17	Comparison of rhinomanometric variables between males and females in the anomaly sample before treatment	98
18	Comparison of rhinomanometric variables between the laminar and turbulent components of NAR in males and females in the anomaly sample before treatment	99
19	Comparison of rhinomanometric variables between males and females in the anomaly sample after treatment	100
20	Comparison of rhinomanometric variables between the laminar and turbulent components of NAR in males and females in the anomaly sample after treatment	101
21	Comparison of rhinomanometric variables between the control sample and the anomaly sample before treatment	102
22	Comparison of rhinomanometric variables between the laminar and turbulent components of NAR between the control sample and the anomaly sample before treatment	103
23	Comparison of transverse cephalometric dimensions between males and females in the control sample	107
24	Comparison of transverse cephalometric dimensions between males and females in the anomaly sample before treatment	108
25	Comparison of transverse cephalometric dimensions between males and females in the anomaly sample after treatment	109
26	Comparison of transverse cephalometric dimensions between the control and anomaly samples before treatment	110

Table	Title	Page
27	Comparison of head posture variables between males and females in the control sample	112
28	Comparison of head posture variables between males and females in the anomaly sample before treatment	113
29	Comparison of head posture variables between males and females in the anomaly sample after treatment	114
30	Comparison of head posture variables between the control sample and the anomaly sample before treatment	115
31	Comparison of airway dimensions between males and females in the control sample	119
32	Comparison airway dimensions between males and females in the anomaly sample before treatment	120
33	Comparison airway dimensions between males and females in the anomaly sample after treatment	121
34	Comparison airway dimensions between the control and anomaly before treatment samples	122
35	Comparison airway dimensions between the male control subjects and the male anomaly before treatment subjects	123
36	Comparison airway dimensions between the female control subjects and the female anomaly before treatment subjects	124
37	Craniofacial morphology - linear values compared between males and females in the control sample	128
38	Craniofacial morphology - linear values compared between males and females in the anomaly sample before treatment	129

Table	Title	Page
39	Craniofacial morphology - linear values compared between males and females in the anomaly sample after treatment	130
40	Comparison of craniofacial linear values between control subjects and anomaly before treatment subjects	131
41	Comparison of craniofacial linear values between male control subjects and male anomaly before treatment subjects	132
42	Comparison of craniofacial linear values between female control subjects and female anomaly before treatment subjects	133
43	Craniofacial morphology - angular values, comparison between males and females in the control sample	137
44	Craniofacial morphology - angular values, comparison between males and females in the anomaly sample before treatment	139
45	Craniofacial morphology - angular values, comparison between males and females in the anomaly sample after treatment	141
46	Comparison of craniofacial angular values between the control of anomaly subjects before treatment	143
47	Correlations - control sample	145
48	Correlations - anomaly sample	146
49	Nasal Airway Resistance - treatment changes in the anomaly sample	151
50	Nasal Airway Resistance - treatment changes in the laminar and turbulent components in the anomaly sample	152

Table	Title	Page
51	Transverse Cephalometric Dimensions - treatment changes in the anomaly sample	156
52	Transverse Cephalometric Dimensions - treatment changes in male anomaly sample subjects	157
53	Transverse Cephalometric Dimensions - treatment changes in female anomaly sample	158
54	Head Posture - treatment changes in the anomaly sample	161
55	Airway Dimensions - treatment changes in the anomaly sample	164
56	Airway Dimensions - treatment changes in the male anomaly sample subjects	165
57	Airway Dimensions - treatment changes in the female anomaly sample subjects	166
58	Craniofacial linear dimensions - treatment changes in the anomaly sample	169
59	Craniofacial linear dimensions - treatment changes in the male anomaly sample subjects	170
60	Craniofacial linear dimensions - treatment changes in the female anomaly sample subjects	171
61	Craniofacial angular variables - treatment changes in the anomaly sample	174

LIST OF FIGURES

Figure	Title	Page
1	Solow and Kreiborg (1977)	11
2	Typical facial characteristics in a child from the anomaly sample	13
3	Age distribution between males and females in the anomaly sample	33
4	Age distribution between males and females in the control sample	34
5	Age distribution between male subjects in the anomaly and control samples	35
6	Age distribution between female subjects in the anomaly and control samples	36
7	Distribution of the skeletal classification of the anomaly subjects	38
8	RME appliance diagram	39
9	RME appliance in situ	39
10	RME appliance with headgear	40
11	RME appliance with protraction facemask	40
12	RME appliance before activation	42
13	RME appliance after activation	42
14	RME appliance with utility (horizontal)	43
15	RME appliance with utility (vertical)	43
16	Intra oral view before RME	44
17	Intra oral view after RME	44
18	Mercury NR6 Rhinomanometer	47

Figure	Title	Page
19	NAR measurement apparatus	48
20	Sigmoid curve on screen	49
21	Attachment of nasal tube to nostril	51
22	Flange connnector pushed through adhesive tape	51
23	Pneumotachograph and facemask	52
24	Flange connector attachments	52
25	Recording nasal airway resistance (posterior)	53
26	Lateral skull cephalometrics in natural head position	55
27	Postero-anterior cephalometrics	57
28	Cephalometric reference point for head posture, airway and craniofacial morphology	65
29	Cephalometric reference points for mandibular and dento-alveolar structures	66
30	Cephalometric reference points for soft tissue measurement	67
31	Soft tissue reference planes	68
32	Angular head posture variables	72
33	Transverse cephalometric points	74
34	Transverse cephalometric points in numerical sequence	76
35	Postero-anterior cephalometric results - significant differences control/anomaly sample	106
36	Airway dimensions - significant differences control/anomaly sample	118

Figure	Title	Page
37	Craniofacial linear dimensions - significant differences between control/anomaly sample	127
38	Craniofacial angular dimensions - significant differences between control/anomaly sample	136
39	Nasal airway resistance - unilateral and posterior value changes	149
40	Nasal airway resistance - laminar and turbulent changes	150
41	Postero-anterior cephalometric results - significant changes with treatment	155
42	Head posture cephalometric results - significant changes with treatment	160
43	Airway dimensions cephalometric results - significant changes with treatment	163
44	Craniofacial linear variables - significant changes with treatment	168
45	Craniofacial angular variables - significant changes with treatment	173
46	Effect on intranasal transverse dimensions of treatment with RME	177
47	Transverse changes in the maxillary dimensions as a result of treatment with RME	185
48	Significant changes in posterior airway dimensions as a result of treatment with RME	189

ACKNOWLEDGEMENTS

The investigation was carried out in the Department of Preventive Dentistry of the University of Edinburgh and in the Orthodontic Department of Victoria Hospital over the period 1988-1994.

I owe a deep debt of gratitude to Professor Philip Sutcliffe of the Institute of Postgraduate Dental Studies, Edinburgh and to Professor dr.odont.Beni Solow of the Institute of Orthodontics, Royal Dental College, Copenhagen, for their unstinting and unselfish help and guidance over the period of study.

I wish also to thank Professor J A Sandham for his original thoughts and wise counsel.

The statistical calculations were carried out in Edinburgh by Miss B Wohlgemuth, whose expertise and patients are immense. I owe her a huge debt.

The radiographs were exposed by Mrs M Phillips of the Edinburgh Dental Hospital whose skill and good humour never flagged, and the illustrative work was undertaken by Mr D Hunter.

The secretarial work was undertaken by Mrs B Fernie from Victoria Hospital to whom I owe my thanks, and also by Ms P Wood.

Finally I would like to thank all the patients who took part in the study.

DECLARATION

This thesis is the original work of the author,

with the exception of the help and guidance

acknowledged in the text.

J P McDonald

CHAPTER 1

LITERATURE REVIEW

1.1 RHINOMANOMETRY

Rhinomanometry is the measurement of the pressure encountered by air passing through the nasal cavity (Clement 1984). It was introduced by Brown and Claesen in 1877, with an indirect procedure described by Zwaardemaker in 1889 whereby a plain mirror was held underneath the nostrils during expiration, the moisture in the exhaled breath being condensed onto its surface. The size of the patches and the time they took to disappear constituted a measure of the nasal passage. Kayser (1895) suggested a direct method for evaluating the nasal passage based on determination of:

1. the amount of air passing through the nose
2. the pressure in the nose during respiration and
3. the velocity of flow

He pointed out that if any two of these factors are known it is possible to calculate the third. Many methods have been published for the recording and measurement of nasal respiratory resistance including those of Aschan et al (1958); Rasmus and Jacobs (1969); Maran et al (1971); Kern (1973); MacKay (1979); Masing et al (1974); Broms et al (1982); Mygind (1980); Solow and Greve (1980); Gurley and Vig (1982).

The accurate recording of nasal respiratory resistance (NRR) is obviously important if the technique is to be used as a diagnostic and research tool. In addition standardisation needs to be agreed upon so that values gained can be meaningfully compared. Kern (1973, 1981) and Broms et al (1982) proposed some elements of standardisation, but it was not until the 8th Congress of the

European Rhinologic Society in 1980 in Bologna, Italy, and more importantly the International Meeting on Standardisation of Rhinomanometry in Brussels in 1983 that important recommendations were made concerning methods of measurement, terminology, calibration and the elaboration of results (Clement 1984). As far as results were concerned, it was agreed that

a. preference should be given to the expression of the resistance at a fixed pressure rather than at a fixed flow, the reference pressure being 150 pascal.

b. the equation $R = \frac{\Delta p}{\dot{V}}$ was accepted where R = resistance, Δp = the pressure difference and $\dot{V}$ = the airflow.

c. it was not necessary to standardise decongestion techniques and that each Rhinomanometrist should utilise the method of his own choice (normally nasal spray or exercise).

d. for reliable measurements a minimum of 3-5 breaths should be recorded.

Stoksted (1951) utilised rhinomanometry in his work on pre- and post-surgical adenoidectomies of schoolchildren with adenoid problems and described its wider use as a diagnostic tool (Stoksted 1959). He further described the cyclic changes in the nasal airway, a phenomenon first noted in 1895 by the German rhinologist Kayser who described a consistent pattern of congestion and decongestion of the nasal mucosa which he termed the nasal cycle. In further studies Hasegawa and Kern (1977) performed experiments which showed 72% of the subjects demonstrated a clearly defined nasal cycle, with a resistance difference of 20% between the two sides right and left reversing or changing sides at least once for two consecutive calculations

during the seven hour testing time. The authors further suggested that normal individuals are not usually aware of this phenomenon because the total nasal resistance usually remains fairly constant and is in fact less than the resistance of either one of the individual nasal passages. In the present study 0.1% zylomethazoline hydrochloride as a nasal spray was administered to the subject one half hour before each recording session to eliminate the cyclic turbinate engorgement (Lenz et al 1985) and any nasal congestion associated with infection or allergy, hence establishing a free airway (Henriksen and Wenzel 1984).

Stoksted (1959) suggested that the resistance in the nose was determined by the two factors, one being the size of the internal orifice and the other the erectile or cavernous tissue of the turbinates. He pointed out that on each inspiration the nasal wings moved outwards dilating the internal orifice and reducing the pressure during the inspiration phase, a movement controlled by the levator labii alaeque nasi muscle (Van Dishoeck 1942). Opinions vary however as to the location of the nasal valve. Mink (1920) applied the term to the main site of nasal resistance placing it at the junction of the upper and lower lateral alar cartilages.

Proctor (1977) located the valve to the region lying between the junction of the upper and lower lateral cartilages and the pyriform aperture. Further studies by Haight and Cole (1983) showed that the main air flow resistance is normally confined to a short nasal segment of a few millimetres situated in close proximity to the junction of the cartilaginous vestibules and the rigid bony cavity of the nose.

Aschen et al(1958) used a small mask placed over the nose in order to measure anterior nasal resistance, calculating it by utilising pressure flow equation $NRR = \frac{\Delta p}{\dot{V}}$. These important experiments form the basis of present methodology, even though the suggestion that nasal resistance could be measured in a single nostril by obstructing

the other with a cotton wool roll is questionable given that each anterior measurement is independent of the pharyngeal component. The technique however proposed by Ashen et al (1958) was used by Linder-Aronson (1970) in a study to measure nasal airflow in subjects with enlarged adenoids, before and after adenoidectomy. He demonstrated that nasal airflow at a fixed pressure was low in children with enlarged adenoids, high in those with small adenoids, and that airflow increased and significant changes occurred in the dentition after adenoidectomy in children who had been mouth breathers pre-operatively because of nasal obstruction. The size of the nasopharyngeal cavity also changed in children who switched from mouth to nose breathing after adenoidectomy.

Inglestedt et al (1969) developed the technique of Ashen and co-workers to measure total or bilateral resistance measurements, but since nasal resistance increased with flow rate the measurements were made at a fixed flow rate to facilitate comparisons. Fischer (1970) proposed a technique for measurement of nasal resistance of both right and left nasal cavities. He measured pressure differences at the one nostril while measuring a flow in the other hence enabling more accurate calculations of resistance of right and left components, greatly improving the diagnostic value of the rhinomanometer. Kortekangas (1972) used the same technique to compare the differences between values obtained by rhinomanometry for anterior (unilateral) and posterior (bilateral) measurements. Bachman (1973, 1976, 1984) proposed a threshold value utilising a fixed pressure, later agreed at 150 pascal.

A modification of the above techniques for anterior measurements has been used in this study together with the advantages of recent computer technology (Solow and Sandham 1989). These researchers further measured the values for laminar (K1) and turbulent (K2) components of the airflow (Rohrer 1925).

Courtiss and Goldwyn (1983) attempted to measure the effects of nasal surgery on the laminar/turbulent flow pattern but came to the conclusion that rhinomanometry was not a reliable method of doing so. Subsequently Solow and Sandham (1991) tested a sample of 20 dental students with no history of nasal airway obstruction with a view to describing the relative contributions of laminar and turbulent flow to the total pressure drop across the nose, utilising a Rohrer programme. (See Table 1). They discovered that in unilateral breathing there was a predominance of turbulent flow but on testing the bilateral breathing a switching of airflow characteristics occurred with a marked reduction in the turbulent components of flow. The authors suggested that the Rohrer equation coefficients might provide information about nasal airflow which are physiologically more appropriate than conventional resistance calculations, which are based on a single point on the rhinomanometric pressure flow curve.

Nasal resistance in normal children has been studied by Solow and Greve (1980), Saito and Nishihata (1981), and Principato and Wolf (1985), hence establishing norm values against which the nasal resistance values of the anomaly sample of the present study can be compared. These are summarised below in Table 2.

TABLE 1

NASAL AIRFLOW CHARACTERISTICS IN A NORMAL SAMPLE

Study	Subjects	Age Range	Results
Solow and Sandham (1991)	20 (8 male, 12 female)	22.9 years to 27.8 years	Unilateral NAR 300 Pas/L/S Bilateral NAR 250 Pas/L/S Unilateral K1-113 K2-807 Bilateral K1-147 K2-348

TABLE 2

NORMAL VALUES FOR NASAL AIRWAY RESISTANCE

Study	Subjects	Age Range	Mean NAR	Significance
Principato & Wolf (1985)	498 (236 female, 262 male)	4 to 16 years	$CmH_20/L/sec$ 4 yrs - 8.28 ↓ 16 yrs - 3.18 (Ant only)	NAR varies inversely with age - highly significant. 95% confidence level
Solow & Greve (1980)	17 (11 female, 6 male)	8 to 14 years	$CmH_20/L/sec$ Post - 0.15 Ant (R) - 1.19 Ant (L) - 2.96	Mean differences not significant at 5% level
Saito & Nishihata (1981)	397 (212 female, 185 male)	5 to 17 years	At flow rate 31 per minute Ant NAR 700 pas/L/sec at age 5-8 300 pas/L/sec at age 16	N/S

1.2 HEAD POSTURE, CRANIOFACIAL MORPHOLOGY AND NASAL AIRFLOW

As early as the 1860s anthropologists realised that for cephalometric studies skulls had to be orientated in a similar way to the natural head position in the living, to make any comparison valid. Von Baer and Wagner (1861) and Broca (1862) decided that a horizontal or vertical reference line outside the cranium should be used, preference being given generally to the horizontal. In 1884 the Frankfort horizontal plane was adopted at the Craniometrical Conference in Frankfurt.

With the advent of cephalometric radiography in the 1930s this plane was utilised as the basis for many analyses. As research utilising cephalometric analysis developed it became important for a standardised natural head position to be used, and in 1957, Bjerin utilised photographs of the facial profile tracings of the enlarged photographs on the cephalometric tracing. Linder-Aronson in 1979 placed a horizontal pencil mark on the cheek of a patient standing in a relaxed position outside the cephalometer in front of a mirror. Once inside the cephalometer the head was positioned with the pencil mark and a projected horizontal light beam superimposed. Vig et al (1980) taped a device containing a radio-opaque fluid level to the subject's head after obtaining the self balance position. Once inside the cephalometer the meniscus was paralleled to a wire. However these methods do not take into account cervical column position.

Solow and Tallgren (1971a,b) utilised a method based on a natural body posture, followed by a procedure in which the patient finds the natural head position by utilising a mirror to enable him to look straight into his own eyes. Using this technique it is possible to measure the position of the head in relation to the true vertical, as well as in relation to the cervical column. Siersback-Nielson and Solow (1982) successfully

tested this method for reproducibility as did Sandham (1988). Cook (1990) undertook a five year longitudinal study of the stability of natural head posture, and found that after an initial deterioration over the first year, the variance of NHP (9.24°) remained significantly less than the variance of intracranial reference points to the vertical (25° to 36°).

The availability of a reliable and reproducible method of measuring natural head and cervical column position is a prerequisite for research into the complex interaction between head posture, craniofacial morphology and airway adequacy. Schwartz (1926) suggested a relationship between head posture and craniofacial morphology when he attributed the development of a Class II malocclusion to hyperextension of the head relative to the cervical column during sleep. Gresham and Smithels (1954) supported this hypothesis; they noted a larger prevalence of Class II malocclusion in subjects with "poor neck posture" as did Bjork (1955). In 1977, Solow and Tallgren in a detailed study of head posture and craniofacial morphology, noted that the craniocervical angulation showed a higher correlation with morphology than the position of the head in relation to the true vertical. Extension of the head in relation to the cervical column was found to be associated with a large anterior and a small posterior facial height, small anteroposterior craniofacial dimensions, large inclination of the mandible to the anterior cranial base and to the nasal plane, facial retrognathism, a large cranial base angle and a small nasopharyngeal space. In contrast, flexion of the head showed exactly the opposite. These findings were similar to those made by Opdebeek et al (1978) and Marcotte (1981). With regard to the relationship between airway adequacy and type of malocclusion, Watson et al (1968) found no association between airway adequacy and type of malocclusion or craniofacial morphology. Linder-Aronson (1970) demonstrated that patients with upper airway obstruction due to enlarged adenoids had a significantly different craniofacial morphology than that of a control group. The

effect on the dental structures included retroclination of the lower incisors and reduction of the overjet, with a narrow upper arch between the first molars often resulting in a crossbite. These patients were obligate mouth breathers (Schweiger 1966).

After adenoidectomy, Linder-Aronson (1974,1975) found that the differences in morphology originally seen between the sample and the control group decreased significantly, this indicated a direct relationship between craniofacial morphology and adenoidal obstruction. Linder-Aronson suggested that in mouth breathing the tongue position is lowered and when adenoids are removed the resting tongue position may be raised resulting in reversal of the anomaly trends. The relationship between craniofacial morphology and rhinomanometrically measured airway adequacy in adenoid subjects has been subsequently shown by Bushey (1977), and the relationship between craniofacial morphology and radiographically measured nasopharyngeal airway adequacy has been demonstrated by Sosa et al (1982). As well as research into the effect of adenoids on the airway, other airway anomalies have been studied. Respiratory obstruction has been shown in patients with cleft lip and palate by Drettner (1960), Warren et al (1969) and Sandham and Solow (1988). Particularly pertinent to the present study was the improved nasal airflow in orthodontic patients after rapid maxillary expansion as demonstrated by Hershey et al (1976) and Loreille and Bery (1981).

In order to explain the similarity between the craniofacial morphology of those subjects with a large craniocervical angulation and those with obstructive airway due to enlarged adenoids, Solow and Kreiborg (1977) suggested an hypothesis to account for the association between head posture, craniofacial morphology and airway obstruction; this has been termed the control hypothesis. They suggested a circular chain of interactions involving

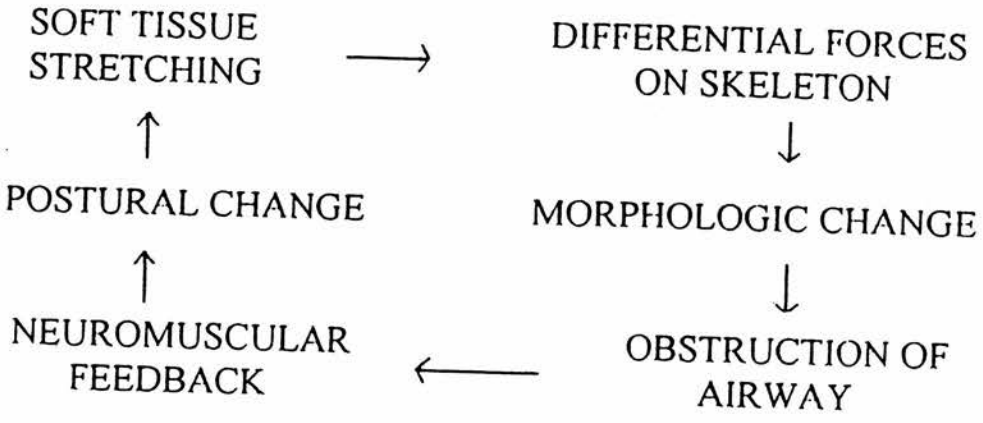


Figure 1
Solow and Kreiborg (1977)

a. a change in airway adequacy

b. neuromuscular feedback

c. a change in craniocervical angulation

d. passive stretching of the soft tissue layer of the face and neck

e. morphologic change resulting in "adenoidal facies". (see Figs 1 and 2).

In 1979 Solow and Greve demonstrated the association between craniocervical angulation and nasal airway resistance in a group of children before and after adenoidectomy. The findings demonstrated that a large craniocervical angulation was seen in conjunction with a large NAR in the subjects before adenoidectomy, the NAR and craniocervical angulation reducing significantly after the operation, there being a reduction of 2° in craniocervical angulation and in the position of the head in relation to the true vertical some two months after adenoidectomy. Woodside and Linder-Aronson (1979) performed similar studies with similar results, as had Ricketts (1968). The relationship between head posture and airway adequacy was also demonstrated experimentally by Vig et al (1980). These findings confirmed the control hypothesis.

Solow et al (1984) examined three sets of associations in a non-pathological group of subjects with no history of airway obstruction. The aim of the study was to examine the predicted association between head posture, craniofacial morphology and airway adequacy. Moderate correlations were discovered, enough to indicate the presence of a general control mechanism in craniofacial development.Given the relationship between airway adequacy and craniofacial morphology and between airway adequacy and craniocervical posture demonstrated by Solow et al (1984), RME would be expected to cause changes both in craniocervical posture and conceivably in craniofacial morphology. This has not been investigated to date.

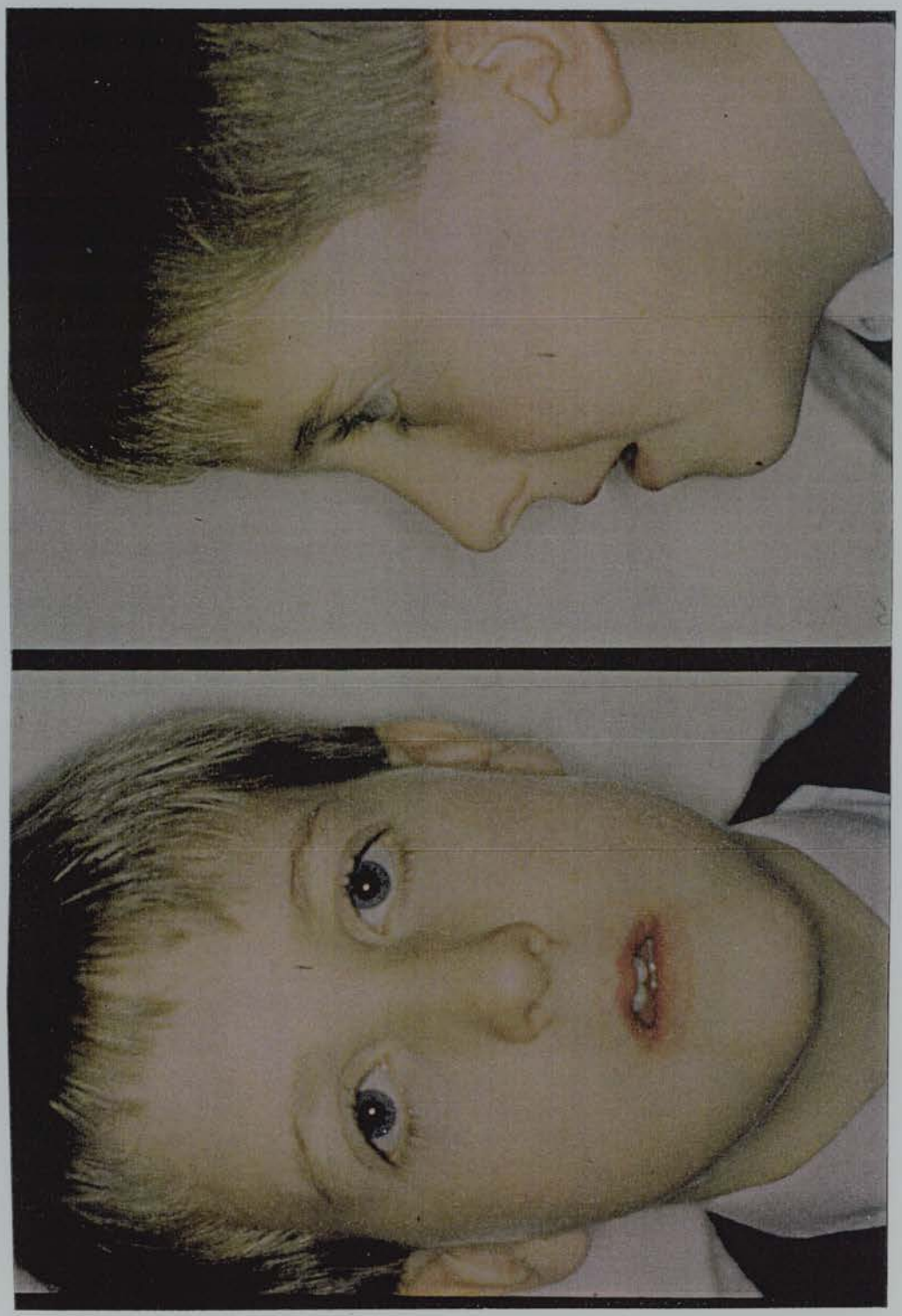


Fig. 2 Typical facial characteristics in a child from the anomaly sample

1.3 RAPID MAXILLARY EXPANSION

History

Rapid maxillary expansion is not a new technique, the first published work appearing in 1860 when E H Angell described the rapid expansion of the upper arch to provide space for maxillary canines. The main supporters of the technique at that time however were not Orthodontists - the most vociferous supporter being Brown (1909), a noted Otorhinologist who published in the Dental Cosmos supporting claims that rapid maxillary expansion allowed the straightening of a deviated nasal septum and provided relief of hypertrophied conditions of nasal and pharyngeal mucous membranes. Pfaf (1905) was of the opinion that routine orthodontic expansion of the dental arch lowered the palatal vault and induced straightening of the nasal septum, in turn moving the septum away from the turbinate bones and permitting an increased air volume. In the early 1900s many articles appeared pointing to the inter-relations of certain orthodontic and rhinological treatments and emphasising that rapid maxillary expansion in particular had consequences far beyond the teeth and mouth.

Since that time, the procedure has gone through periods of popularity and decline, particularly in comparison to slower methods of expansion. A review of the contemporary literature indicates that there were numerous disagreements as to the indications and efficacy of rapid maxillary expansion. Angle (1907) supported slow maxillary expansion whilst C H Hawley (1912) and H A Pullen (1912) opted for RME.

Aetiology

The aetiology of lateral discrepancies resulting in either unilateral or bilateral posterior crossbites can be either general or environmental. Harvold et al (1973) in their experiments on the development of dental malocclusions were able to create narrow maxillary dental arches in rhesus monkeys by converting them from nasal to obligatory oral respiration. This environmental approach was supported by Graver et al (1975).

Histology

Sutures - As the midpalatal suture is of paramount importance in any study involving rapid maxillary expansion, close examination of its composition and characteristics both before and after rapid expansion is essential.

Development of a normal suture without RME - Melsen (1975) traced the development of the suture from birth to adulthood by histologic means utilising material from human cadavers. She found that in infancy the suture, looked at in a vertical coronal section, is traced the development of the suture from birth to adulthood by histologic means utilising material from human cadavers. She found that in infancy the suture, looked at in a vertical coronal section, is Y-shaped binding the vomer with the palatine processes. As the suture ages the junction between the three bones assumes more of a T-shape and by adolescence the sutural course may become so interdigitated that jigsaw-like interlocking may take place. Melsen stresses that this latter developmental characteristic is unique to humans, so the results of animal experiments cannot be directly transferred to man. Melsen (1972) however working on human biopsy material obtained by a trepanning technique revealed much in common with animal findings up to the period of maximal pubertal growth.

Human autopsy material was also used by Persson and Thilander (1977) to examine the timing and ossification rates. They found the earliest closure to be in a 15 year old female whilst the oldest unossified suture was in a 27 year old

female, a greater degree of obliteration occurring posteriorly rather than anteriorly. The fact that the suture starts to ossify posteriorly (Davida 1926) is important when planning surgical intervention in sutural division.

Suture after RME - histologic studies of the suture opening by Derichsweiler (1953) and Cleall et al (1979) have demonstrated rapid cellular adjustments at the intermaxillary suture, new bone being formed in the palatal void. Ekstrom et al (1977) found that the mineral content within the suture rose rapidly during the first month after the completion of suture opening, the mineral content of the adjacent bone decreasing sharply through the first month but returning to its initial level within three months. Ten Cate et al (1977) found that the separation of the suture involved tissue injury which was followed by repair and regeneration of the suture.

Brin et al (1981) investigated the effects of age on sutural cyclic nucleotides, and came to the conclusion that the bone cells of older animals are less responsive to tensile forces than the corresponding cells in younger animals hence suggesting that the reasons for differences in clinical response between various age groups may result from variations in cellular biology.

Techniques

Removable expansion plates are not effective if significant skeletal changes are required, even though limited midpalatal separation has been recorded (Krebs 1964). The use of removable appliances can only be justified in the deciduous or early mixed dentition. The main problem, as indeed with some of the fixed palatal expanders, is the lack of rigidity (the resistance to rotation). Nearly parallel opening by a rigidly fixed appliance is required, or the dento-alveolar components will tilt buccally diminishing the amount of basal bone expansion that is necessary. Chaconas (1975) showed that the appliance form determines the

shape of the expansion, further demonstrating the ineffectiveness of the removable expander.

Angell (1860) recommended a fixed expansion appliance utilising a double jack screw with opposing threads, and succeeded in widening the maxillary arch of a 14 year old girl by ¼" in two weeks. Since then, appliances cemented to the teeth either in the form of bands or cap splints have been the vehicles of choice. Again, rigidity is of prime importance so the quadhelix (Ricketts 1957) which is attached only to the maxillary first molars can only be effective in cleft palate cases. The Hyrax, Haas, Derichsweiler or Biederman appliances, which are attached to both first permanent molars and the first permanent premolars certainly have the rigidity to separate the palatal shelves and are widely used. However Barbar and Sims (1981), Langford and Sims (1982) and Odenrich et al (1982) all recorded marked buccal root resorption in first permanent premolars when these were used as buttresses for the Biederman rapid maxillary expanding appliances. These defects tended to gradually repair when the pressure was relieved.

Silver/copper alloy cast cap splints, as described by Grossman (1963), have a number of advantages over band retained appliances. Cast splints, which are extremely rigid, spread the load levels over the whole buccal tooth bearing area and also relieve intercuspal locking whilst the expansion is taking place. The disadvantage of poorer oral hygiene can be minimised by irrigation beneath the palatal acrylic surface of the appliance using a water syringe supplied to the patient.

The screws used in rapid maxillary expander appliances are normally Hyrax (Dentoraum 602-813), Glenross VI or Leone 620 all of which give between 11 and 18mm of expansion. Isaacson et al (1964) however utilised a springloaded screw called a Minne Expander (Minnesota Dental School). More recently bonded full coverage appliances had been described (Mondro 1977, Howe 1982 and Spolyar 1984).

Forces and Relapse

Rapid maxillary expansion takes place when the lateral force applied to the teeth and maxillary alveolar processes exceeds the limits needed for orthodontic tooth movement. This pressure then acts as an orthopaedic force, compressing the periodontal ligament, deforming the alveolar processes and opening the midpalatal suture.

The forces generated by rapid palatal expanding appliances are high. These forces have been investigated by Isaascson (1964) who used a strain gauge to study the forces produced. Isaacson found there may be up to 20lb of force applied during suture opening and it was his view that the heavy forces in suture opening provided minimal tooth movement and maximum reposition of the maxillary segments. He also believed that in order to prevent relapse of the bone segments these heavy forces must be allowed to dissipate throughout the whole maxillary complex before any appliances are removed. With such heavy forces it is reasonable to assume that the effects of the procedure spread widely into the bones of the facial complex.

Mesnard (1929) reported the use of fixed appliances for separation of the maxilla and described some of the accompanying changes. In addition to dislocation of the maxilla in the midline, he documented the lowering of the vault of the palate and floor of the nose, the straightening of the nasal septum and the restoring of nasal permeability. An examination of occlusal films by Wertz (1970) showed that the opening of the midpalatal suture extends through the horizontal plates of the palatine bones but only to a small degree. Kudlick (1973) working on a human dried skull came to the conclusion that it was the sphenoid bone not the zygomatic arch that was the main buttress against maxillary expansion. He emphasised that the pterygoid plates of the sphenoid, although bilaterally positioned, do not have a mid-sagittal suture that allows them to be displaced laterally. This limiting effect of the pterygoid plates of the sphenoid

minimises dramatically the ability of the palatine bones to separate at the mid-sagittal plane. The pterygoid plates can only bend to a limited extent as pressure is applied to them, and their resistance to bend increases dramatically in the parts closer to the cranial base where the plates are much more rigid (Timms 1980).

As far as the separation of the maxillary segments is concerned, the maxillary suture was found to separate in a pyramidal shape, the base of the pyramid located at the oral site of the bone (Haas 1961,1970). The relation between the amount of sutural separation and the amount of molar expansion was studied by Krebs (1964), who placed implants in the alveolar processes lingual to the upper canines and along the infra-zygomatic ridge, buccal to the first upper molars. He found that the amount of sutural opening was equal to or less than one half of the amount of dental arch expansion. He further found that the sutural opening was on average more than twice as large between the incisors as between the molars. He also found that although dental arch width was maintained during fixed retention, the distance between implants in the infra-zygomatic ridges decreased through the first three months of fixed retention by an average of 10-15%, this relapse continuing during retention with removable appliances so that after an average period of fifteen months only 70% of the infra-zygomatic maxillary width increased was maintained.

The final position of the maxilla was investigated by Haas (1961) and Wertz (1970). They both found it to be frequently displaced downward and forward but the final position was unpredictable due to an element of relapse that could be partial or complete. In addition the maxillae were found to tip relative to one another around a fulcrum approximately at the fronto-maxillary suture. This would explain the increased width gain at the dental rather than the sutural level.

One of the most obvious signs accompanying the opening of the midpalatal suture is the opening of a diastema between the maxillary central incisors, an event about which both the parents and the patient must be prewarned. The incisors separate approximately one half the distance of the opening of the expansion screw (Haas 1961) but the amount of separation between the central incisors cannot be reliably used as an indicator of the sutural opening. After this separation, the incisor crowns converge due to the force from the stretched trans-septal fibres. Once the crowns contact, the fibres continue to pull giving a tendency for the maxillary central incisors to be extruded and become more upright or tip lingually (Wertz 1964), thus shortening the arch length. This latter movement can be forestalled by employing sectional fixed appliances utilising tubes soldered to the rapid maxillary expansion appliance, a technique developed for this present study. The maxillary posterior teeth have a tendency to tip buccally as force is applied.

Skeiller (1964) and Hicks (1978) suggest that slower maxillary expansion is less prone to relapse because the lower force levels cause less alveolar plate warpage and less disruption of the adjacent bones. Wertz (1970) found that rapid maxillary expansion led to an increase in width of the maxilla due to a lateral rotation of each half, this rotation tending to return to normal after termination of active expansion. Timms (1976) re-examined twenty six patients five years out of retention; a mean relapse of intermolar width of 4mm was observed giving a mean residual expansion of 44%. Wertz and Dreskin (1977) stated that maxillary skeletal width can be expanded with no relapse in younger patients, older patients having a significant tendency to relapse. Linder-Aronson and Lindgren (1979) re-examined twenty three patients and found that the final increase in width between the upper first molars five years post-retention was 45% of that initially achieved by rapid maxillary expansion could be found. The role of

the palatal muco-periosteum in relapse was investigated by Cotton (1978) who suggested that relapse between the maxillary first molars may be related to the stretched fibres of the attached palatal mucosa. Maguerza and Shapiro (1980) attempted to relieve the stretch of the muco-periosteum after expansion by making incisions along the palate down to the cortical bone, some 3mm away from the teeth. However the incisions did not effectively reduce the amount of relapse.

As to the length of retention time, providing this is in excess of the three months suggested by Ekstrom et al (1977), there would appear only to be a weak association between the residual expansion and length of retention.

Greenbaum and Zachrisson (1982) examined the effect of palatal expansion therapy on the periodontal tissues by comparing patients with orthodontic treatment alone, rapid maxillary expanding appliances, and slow (quadhelix) palatal expanders. They found that the differences among the groups were not significant and clinically of small magnitude.

Secondary effects of RME on Mandibular Arch Width

The effects of rapid maxillary expansion on the mandibular arch width appear to be unpredictable, with Gryson (1977) recording no significant changes in the trans-canine and trans-molar mandibular widths whereas Sandstrom et al (1988) discovered statistically significant expansion of the inter-canine and inter-molar widths. Wertz (1977) observed mandibular intermolar width increased at the completion of maxillary suture opening and Haas (1965,1970) recorded that the mandibular teeth became uprighted as the maxillary teeth expanded.

Anteroposterior orthopaedic forces

Immediately after the palate has been split, with concomitant breakage of adjacent sutures, it would seem to be an attractive proposition to apply orthopaedic forces to the maxillae, in order to move them mesially or distally. Haas (1961) applied forces to the maxilla following RME and reported an enhanced response. McNamara (1987) and Wemmer (1988) used Delaire face masks attached to the rapid palatal expansion appliance to bring post-normal maxillas forward immediately after rapid maxillary expansion. It is generally accepted that the midpalatal suture ossifies in the mid teens, after which rapid maxillary expansion becomes more problematical and unpredictable.

Surgical aspects

Different surgical approaches can be used to help correct maxillary constrictions with or without using a rapid maxillary expansion appliance. Surgery is particularly effective in overcoming the strong resistance of the maxillary complex after growth has completed. The surgical palatal expansion can be accomplished by surgically moving the maxilla with lateral corticotomies (Lines 1975), by surgically undermining the maxillae to facilitate expansion using an RME appliance, (Glassman 1984 and Alpern and Yurosko 1987) or by surgical separation of the palatal shelves (Bell and Epker 1976 and Kraut 1984). Mossaz et al (1992) have described a technique of unilateral and bilateral corticotomies for correction of maxillary transverse discrepancies.

It is worth remembering however that surgical procedures to expand the palate without rapid maxillary expansion run the risk of severe stretching of the palatal muco-periosteum, with consequent tendency towards relapse.

Current best practice for these patients who have a fused midpalatal suture is to employ surgery to separate the suture followed by semi-rapid (one turn per day) expansion with a cast splint appliance.

1.4 RAPID MAXILLARY EXPANSION AND NASAL RESPIRATORY RESISTANCE

The two key questions that need to be asked when investigating the changes in nasal respiratory resistance associated with RME are:

1. Is there a change in NRR - and if so is it of clinical significance?
2. If the change is of clinical significance how permanent is it?

There can be no doubt that anatomically there is an increase in the width of the nasal cavity immediately following expansion, particularly at the floor of the nose adjacent to the midpalatal suture (Haas 1961). Haas investigated a sample of 80 cases of which 8 were over 20 years old. His work was supported by Wertz (1970).

The maxillae separate, and the outer walls of the nasal cavity move laterally effecting an increase in intra-nasal capacity. Pavlin et al (1984) using laser holography, albeit on dried skulls, calculated the average nasal cavity width gain to be 1.9mm while Gray (1975) suggested that at the important level of the inferior turbinates, the width gain can be as much as 8mm. Montgomery, Vig et al(1979) in a computed tomography study found the effects of RME on the nasal cavity to be progressively less towards the back of the nasal cavity, a finding which correlates with histological examination. Warren et al (1987) concerning the small increase in binasal width (average 0.5mm) pointed out that the airflow varies inversely as the fourth power of the radius of the tube through which it passes, hence a small increase in the radial dimensions of the tube means considerable increases in the flow.

Hershey et al (1976) investigated 17 subjects, 6 male and 11 female, all mouth breathers. The palates were expanded using Biederman appliances and retained for three months after completion of expansion. They reported a reduction of nasal respiratory resistance by an average of 45% after rapid maxillary expansion, and

this was stable for one year after appliance removal. These findings were supported by Turbyfill (1976) who found in his study an average decrease of 53% in nasal respiratory resistance after rapid maxillary expansion. Graber (1975) believes that the improved nasal breathing apparent after RME is only a temporary measure, simply because children have more lymphoid tissue than adults and spontaneous resolution occurs through growth, automatically improving nasal breathing without orthodontic intervention. Wertz (1970) concluded that opening of the midpalatal suture for the purpose of increasing nasal permeability cannot be justified unless the obstruction is shown to be in the lower anterior part of the nasal cavity, and accompanied by a relatively severe maxillary arch width deficiency. Hargerink et al (1987,1989) concluded that due to the high variability of individual response, rapid maxillary expansion is not a predictable means of decreasing nasal respiratory resistance, and found no correlation between the amount of expansion and changes in nasal resistance. White and Woodside (1989) however found an average reduction in nasal airway resistance of 48.7%, which was statistically significant at the $p<0.005$ level. This reduction also appeared stable throughout the post-treatment observation period (maximum one year), and was highly correlated to the initial degree of nasal resistance prior to rapid maxillary expansion. Those individuals with the greater initial resistance tended to have greater reductions in airway resistance following the expansion.

It can be seen from the conflicting results obtained by various workers that the inter-relationship between rapid maxillary expansion and nasal respiratory resistance remains unresolved. In part it may be due to the differing methods of obtaining rapid palatal expansion, and to methods of measuring nasal respiratory resistance. The aim of the present study is in part to continue research into the inter-relationship between RME and NRR, but in particular to measure any differences that occur in the balance between the laminar and turbulent airflow before and after RME.

1.5 SUMMARY

The adequacy of the nasopharyngeal airway has been found to be related to craniofacial development. Obstruction of the airway by adenoid tissue, nasal septal deviation or abnormal morphology of the area is associated with characteristic changes in craniofacial morphology such as long anterior face height, facial retrognathism and a steep inclination of the mandibular plane often with a high palate and crossbite (Linder-Aronson 1970 and Solow et al 1984).

Some studies have found the changes to be reversible after adenoidectomy which improves nasal airway patency (Linder-Aronson 1974,1975) and a control mechanism for facial growth has been proposed to account for the relationships between airway adequacy, craniofacial morphology and craniocervical postural relationships (Solow and Kreiborg 1977). It is therefore important to be able to accurately measure nasal airway resistance so that the effect of operative procedures in the area, such as rapid maxillary expansion (RME) can be determined.

Nasal airway resistance (NAR) is a measure of airway adequacy. It can be recorded by rhinomanometry, a non-invasive technique which measures the resistance to airflow by simultaneous recording of flow and the pressure drop over the nose (Aschan et al 1958, Massing 1965, Kern 1973, Solow and Greve 1980 and Bachmann 1982). Recent technical advances based on microcomputer technology have made recording easier, but most studies have used threshold values for pressure or flow to calculate nasal airway resistance (Sandham and Solow 1987). Proposals have been made concerning the more accurate determination of Laminar (K1) and Turbulent (K2) flow coefficients (Rhinomanometric Meeting Berlin 1987) using a mathematical model known as the Rohrer equation.

Equipment is now available to enable such recordings to be made. This provides more valuable and accurate data and serves as a basis for improved understanding of the effect of RME on nasal airway adequacy.

The recording by computer of linear and angular variables for craniofacial morphology (derived from co-ordinate data digitised from standardised cephalometric radiographs), is a procedure which has been developed, error tested and utilised in the Department of Preventive Dentistry, Edinburgh University, for a previous study (Sandham 1987) but based on an analysis of craniofacial form by Bjork, and computer programmes developed by Solow (1966). The recording of such variables relating to transverse relationships was digitised from postero-anterior radiographs using software developed specifically for the present study.

An association exists between craniocervical angulation and nasal airway resistance, a large craniocervical angulation being seen in conjunction with a large nasal airway resistance in a group of subjects before adenoidectomy. After the operative procedure, nasal airway resistance and craniocervical angulation was reduced (Linder-Aronson 1984). An alteration in craniocervical and possible cranio-hyoid relationships may therefore be detected in the present study if improvement in airway adequacy due to treatment with rapid maxillary expansion is found.

Previous studies have suggested that maxillary expansion may be justified on airway considerations alone but Warren et al (1987) and Hartgervink et al (1987) both suggest that the technique is not a predictable means of decreasing nasal airway resistance. However in the present study all the subjects in the anomaly group were treated by rapid maxillary expansion (RME) as part of a course of orthodontic treatment for bilateral crossbite.

2. AIMS AND OBJECTIVES OF THE STUDY

The review of the literature has shown that there is relatively little standardised information on Nasal Airway Resistance in children and on the effects of rapid maxillary expansion in those with full transverse cusp bilateral crossbite.

It was the aim of the present study therefore -

1. to compare craniofacial form, head posture and nasal airway resistance between a control sample and a sample of children with full transverse cusp bilateral crossbite and
2. to determine the effect on these parameters of rapid maxillary expansion on children in the anomaly sample

The aim of the study therefore is to investigate -

a. craniofacial form
b. head posture
c. nasal airway resistance

in a group of children aged 10 to 15 years (inclusive) undergoing RME.

AIM 1

To compare the control and anomaly groups at the base line - Time 1 - for a, b and c above.

AIM 2

To determine the changes in the anomaly sample following treatment with RME - Time 2 - in terms of a, b and c above.

The Null hypothesis to be tested are:

AIM 1

i. There will be no difference in the mean values of Nasal Respiratory Resistance, including the values for laminar and turbulent airflow, between the control and anomaly sample.

ii. There will be no difference in the craniocervical angles NSL/OPT and NSL/VER between the control and the anomaly sample.

iii. There will be no difference in the following lateral craniofacial morphology values between the control and anomaly sample

a. linear values:

n-s	sp-pm
n-sp	ss-pm
n-gn	pgn-cd
s-ba	oj
s-pm	ob
sp-gn	

b. angular values:

n-s-ba	ss-n-pg
pm-s-ba	NSL/NL
s-n-sp	NSL/ML
s-n-ss	NL/ML
s-n-sm	NSL/MBL
s-n-pg	ML/RL
ss-n-sm	

c. airway dimensions:

$pm\text{-}ad_1$

$pm\text{-}ad_2$

$pm\text{-}ad_3$

$tu\text{-}ad_3$

iv. that there will be no difference in the transverse craniofacial dimensions between the control and anomaly sample:

CNR-CNM	MIR-MIL
CNM-CNL	MIR-C_2
CNR-CNL	C_2 -MIL
EMR-EML	NASDIM
UMR-UML	MAXDIM
LMR-LML	

AIM 2

i. there will be no change in the mean values of Nasal Respiratory Resistance, including the values for laminar and turbulent airflow, before and after RME.

ii. there will be no difference in the craniocervical angles NSL/OPT and NSL/VER before and after RME.

iii. there will be no change in the following lateral craniofacial morphology values before and after RME.

a. linear values:	n-s	sp-pm
	n-sp	ss-pm
	n-gn	pgn-cd
	s-ba	oj
	s-pm	ob
	sp-gn	

b. angular values:

n-s-ba	ss-n-pg
pm-s-ba	NSL/NL
s-n-sp	NSL/ML
s-n-ss	NL/ML
s-n-sm	NSL/MBL
s-n-pg	ML/RL
ss-n-sm	

c. airway dimensions:

pm-ad_1

pm-ad_2

pm-ad_3

tu-ad $_3$

iv. that there will be no change in the transverse craniofacial dimensions before and after RME

CNR-CNM	MIR-MIL
CNM-CNL	MIR-C_2
CNR-CNL	C_2 -MIL
EMR-EML	NASDIM
UMR-UML	MAXDIM
LMR-LML	

3. CLINICAL MATERIAL AND METHODS

3.1. Clinical Subjects

a. The anomaly study group comprised 72 children, 41 female and 31 male, all within the age group 10-15 years inclusive (see Fig 3). The mean age of the females was 12 years 8 months, and of the males 12 years 9 months (see Table 3). They were all patients that had been referred to Victoria Hospital, or to Edinburgh Dental Hospital by General Dental Practitioners, General Medical Practitioners or Consultant ENT colleagues.

   The criteria for inclusion in the study were that the subjects exhibited a full transverse cusp bilateral crossbite, and had not undergone any previous tonsilar, nasal or adenoidal surgery.

b. The control sample comprised 36 children, 24 female and 12 male, again all within the age group 10-15 years inclusive (see Fig 4). The mean age of the females was 12 years 7 months, and of the males 12 years 5 months (see Table 3). They were all patients that had been referred to either Victoria Hospital or Edinburgh Dental Hospital and were included sequentially if they fulfilled the agreed criteria on age, having no full transverse cusp bilateral crossbite and they had not undergone surgery to the tonsils, nasal passages or adenoids. As far as possible there was matching of the proportions of males and females within each group (see Figs 5, 6).

All subjects included in the study be they anomaly or control were of the same Northern European racial background.

Ethical approval for the study was obtained (see Appendix).

The procedures involved in the study were those normal clinical procedures that would be undertaken for any child, the only exception being the use of non-invasive rhinomanometry on the control sample. All procedures were fully explained to the patients and to their parents and approval requested before continuing. There were no refusals.

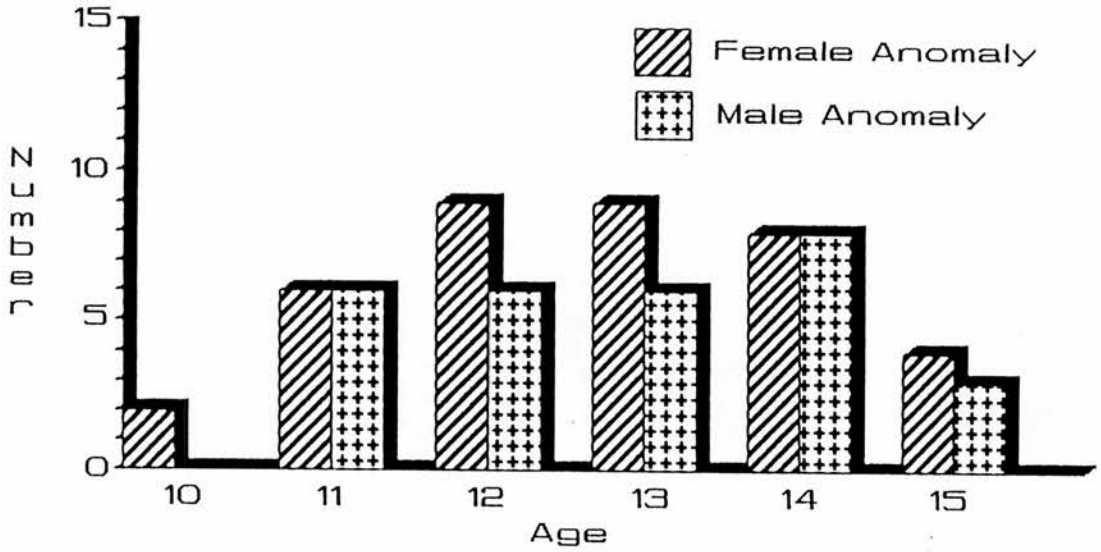
TABLE 3

Age Distribution in each Group

	Number	Mean Age in Years	Standard Deviation
Male control	12	12.46	1.20
Male anomaly	31	12.93	1.32
Female control	24	12.71	1.39
Female anomaly	41	12.79	1.35
Male and Female control	36	12.59	0.18
Male and Female anomaly	72	12.86	0.10

Fig. 3

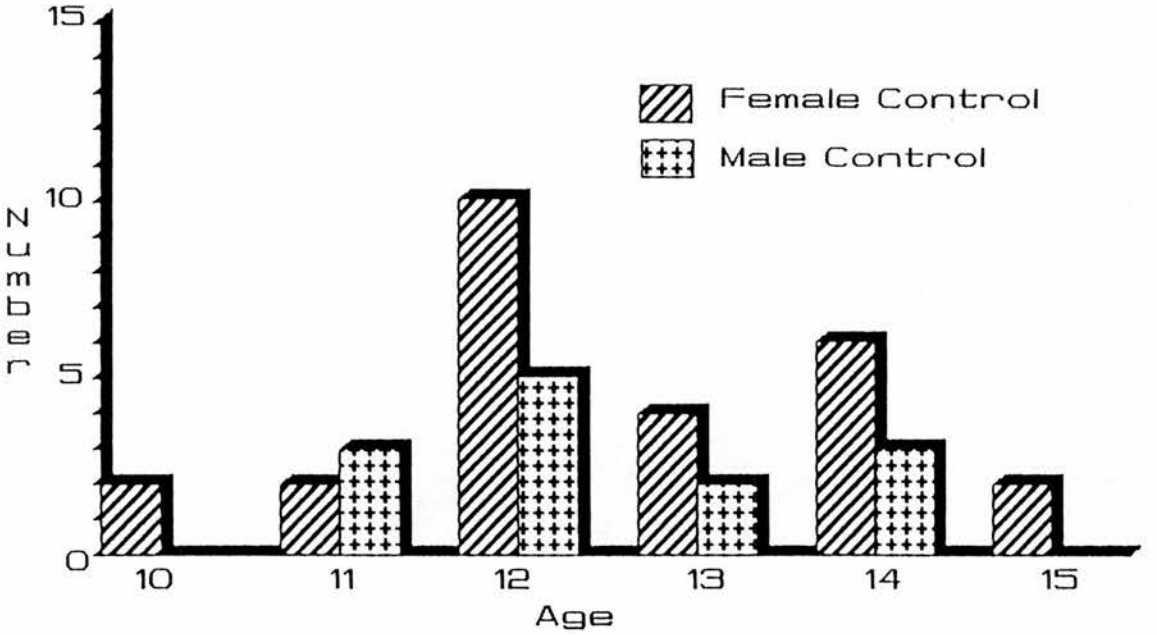
Age Distribution



Distribution of the ages in years of 31 male and 41 female anomaly subjects.

Fig. 4

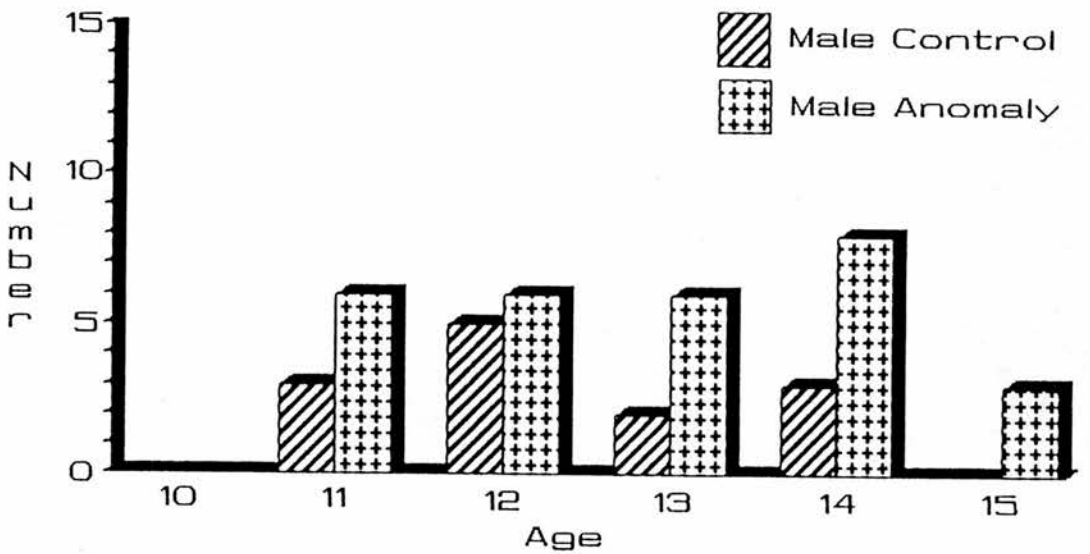
Age Distribution



Distribution of the ages in years of 12 male and 24 female control subjects.

Age Distribution

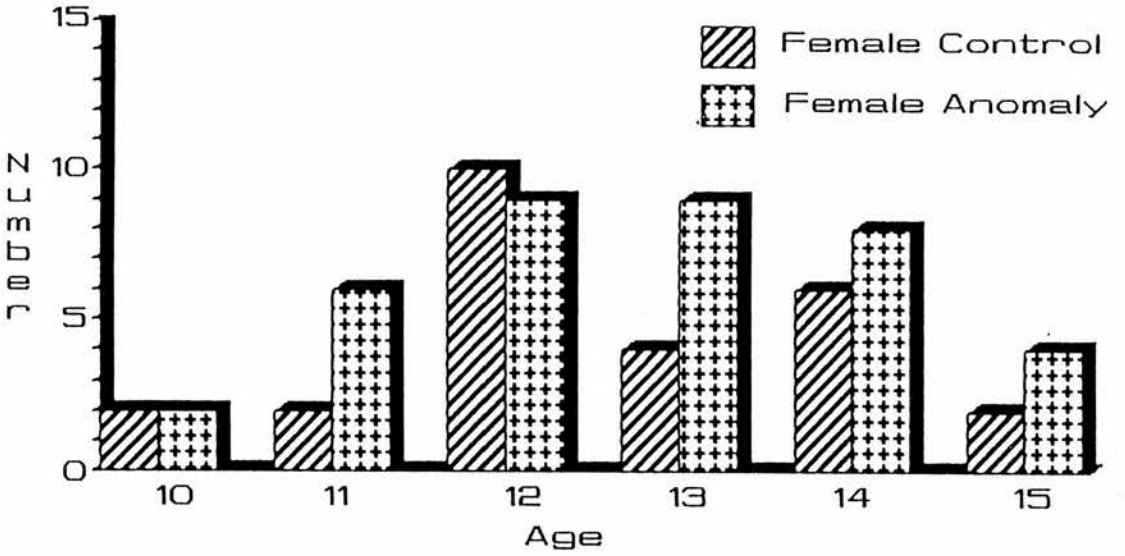
Fig. 5



Distribution of age in years of 12 male control subjects and 31 male anomaly subjects.

Fig. 6

Age Distribution



Distribution of age in years of 24 female control subjects and 41 female anomaly subjects.

3.2 Rapid Maxillary Expansion

The anomaly sample subjects were treated as soon as the clinical necessity arose, both in terms of orthodontics and of nasal airway insufficiency. Orthodontically this normally meant that the maxillary cuspids had erupted, enabling a full transition from rapid maxillary expansion to fixed appliances in order to complete the treatment.

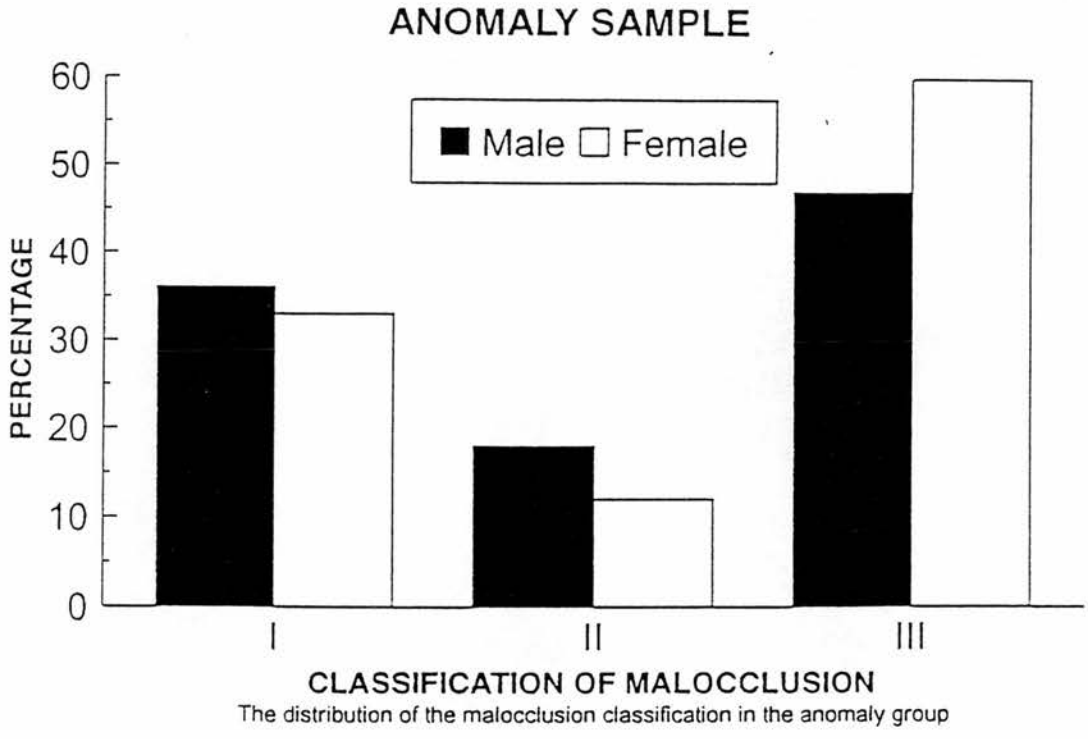
Full baseline records had been obtained at Tim.1 - study models, clinical photographs, PA, OPG and lateral cephalometric radiographs together with rhinomanometric measurements. The rapid maxillary expansion appliance was then constructed. This took the form of a silver/copper alloy splint giving full tooth coverage of 6543/3456, to which were soldered double buccal tubes with hooks. (See Figs 7,8). The tubes were placed anteriorly in 43/34 region to reduce the length of unsupported wire used to align the upper incisors in the later fixed appliance phase. In addition there were holes in the cast splint to facilitate its easy removal. The essential rigidity of the appliance was enhanced by palatal acrylic coverage, and the active expansion provided by a Hirax screw normally 18mm long but in small mouths 11mm.

Modifications of the appliance were used depending on the orthodontic classification of the anomaly patient. (see Fig 7).

In the twenty four Class I anomaly subjects, the standard appliance was used. (see Fig 8,9).

In the ten Class II anomaly subjects, headgear tubes were added to the buccal archwire tubes to facilitate the distalisation of the maxilla once rapid palatal expansion had been undertaken (MacNamara 1988). (see Fig 10).

In the thirty eight Class III anomaly subjects, an additional hook was placed mesial to the archwire tube to allow a protraction facemask to move the maxilla forwards relative to the cranial base (MacNamara 1988). (see Fig 11).



The distribution of the malocclusion classification in the anomaly group

Fig. 7

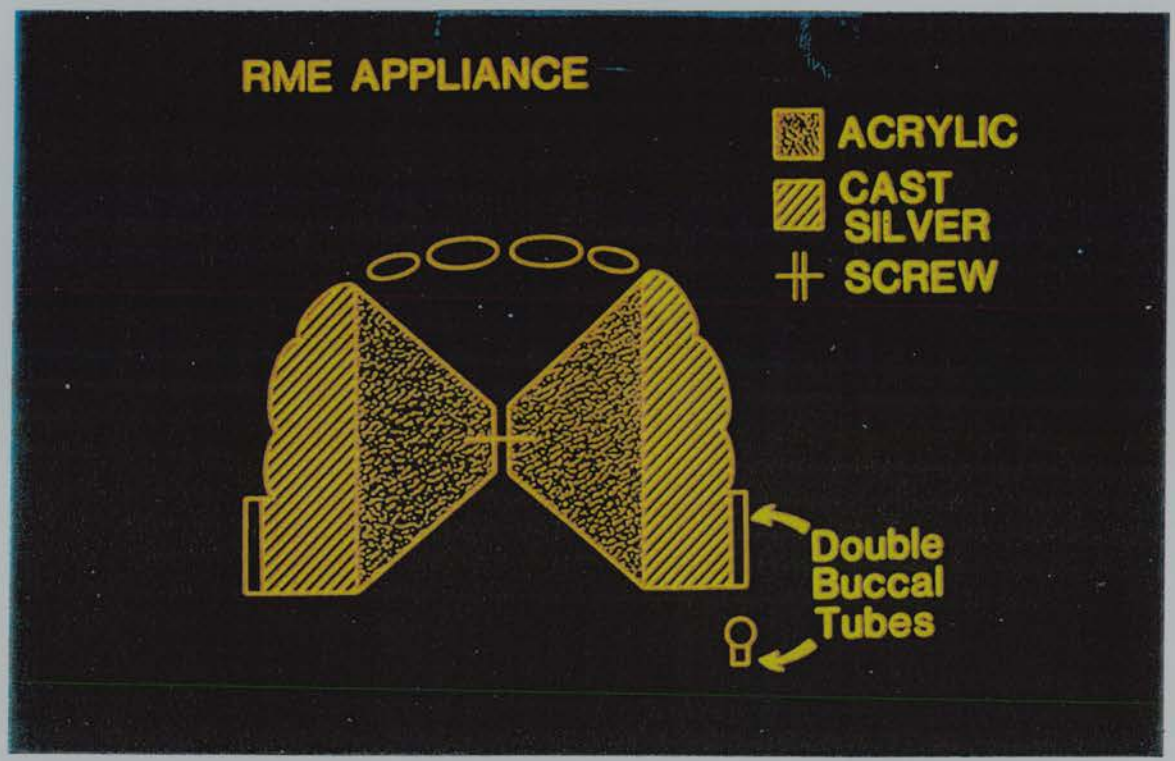


Fig. 8 RME appliance diagram

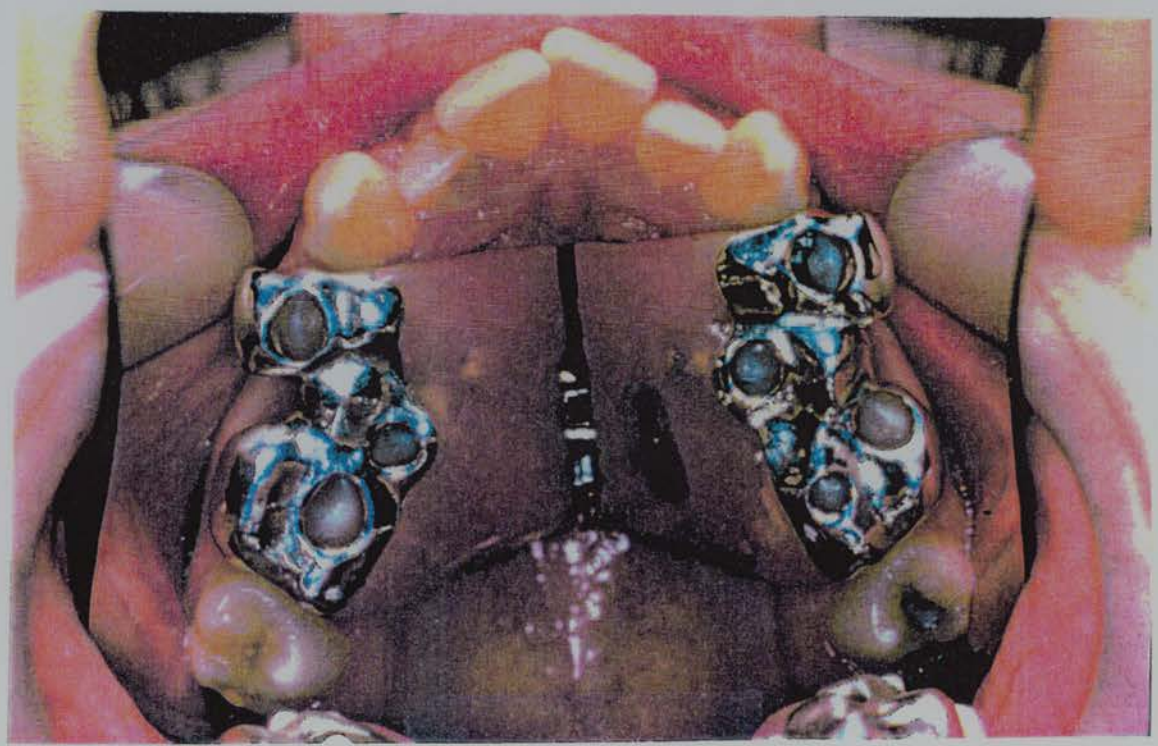


Fig. 9 RME appliance in situ

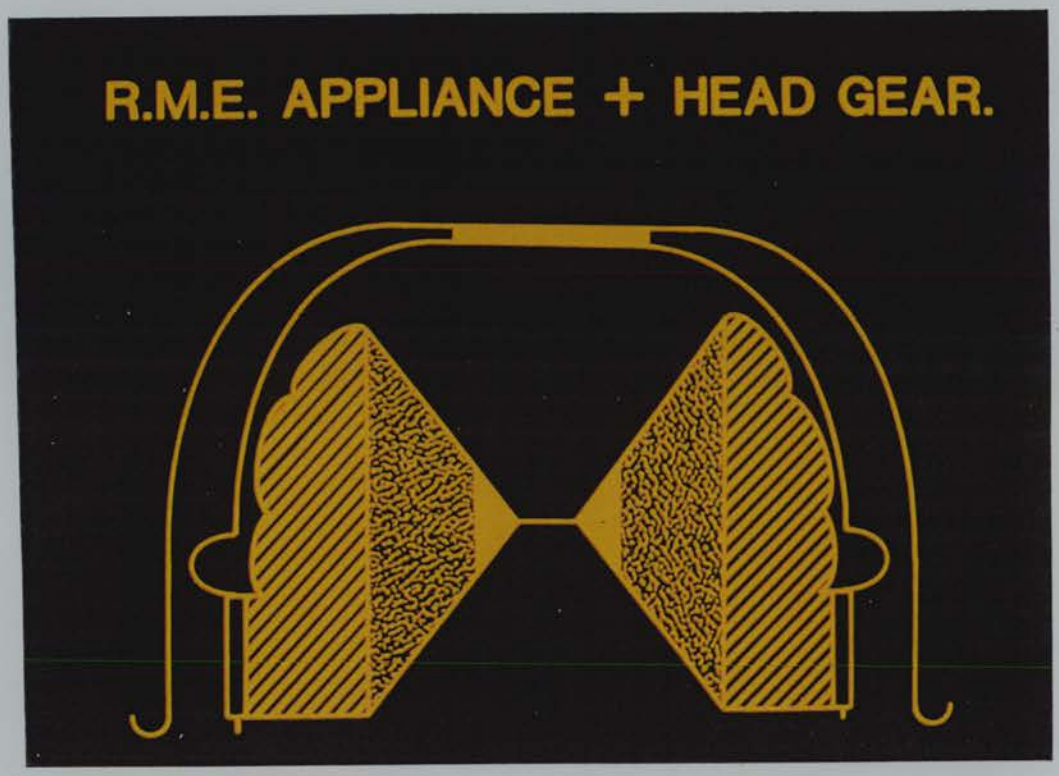


Fig. 10 RME appliance with headgear

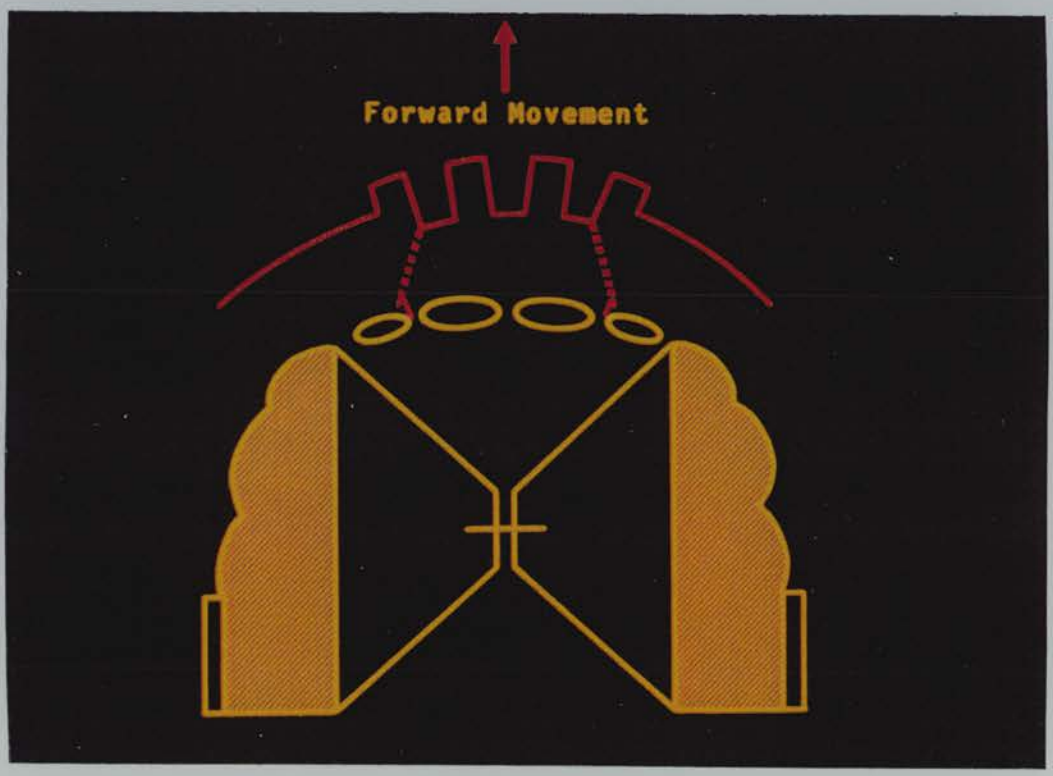


Fig. 11 RME appliance with protraction facemask

The cast splint, unlike either the Quadhelix or Biederman, is the only appliance that gives the rigidity necessary to splint the maxillary midline suture without undue flexing of the maxillary segments or undue tipping of the maxillary teeth.

Once the appliance was checked for fit, the teeth were cleaned by the Dental Hygienist and the splint cemented with glass ionomer cement. (see Fig 12). After one day, the parent (normally) activated the appliance:

- three times per day for the first week (after breakfast, on return from school and before bed)
- two times per day for the second week (morning and evening)
- one time per day for the third week, or until the bilateral crossbite had been slightly overcorrected.

The patient and parent were warned about the midline diastema that appeared between the central incisors. The active part of the rapid maxillary expansion phase of the treatment took on average 3.75 weeks, with a range from 2.25 weeks to 5.5 weeks, and a standard deviation of 0.92. At the end of this time the parents stopped turning the screw (see Fig 13), the appliance was removed, the teeth cleaned and full records obtained (Time 2). The appliance was then recemented and left non-active for three months to enable the midline suture to reossify (Ekstrom et al 1977). During this time any gross anteroposterior maxillary discrepancy was treated by taking advantage of the fluid sutures and placing headgear or a facemask as required.

The anchorage offered by the cast splint was utilised by bonding 21/12 and aligning the teeth with a series of progressively heavier archwires secured posteriorly into the tubes of the cast splint (see Fig 14). Once the incisors had been aligned, and the midpalatal suture reossified, then the cast splintage was removed, the buccal teeth cleaned and then bonded and banded. A heavy utility arch in .016" x .022" stainless steel wire was placed between 621/126 to retain the intermolar width together with

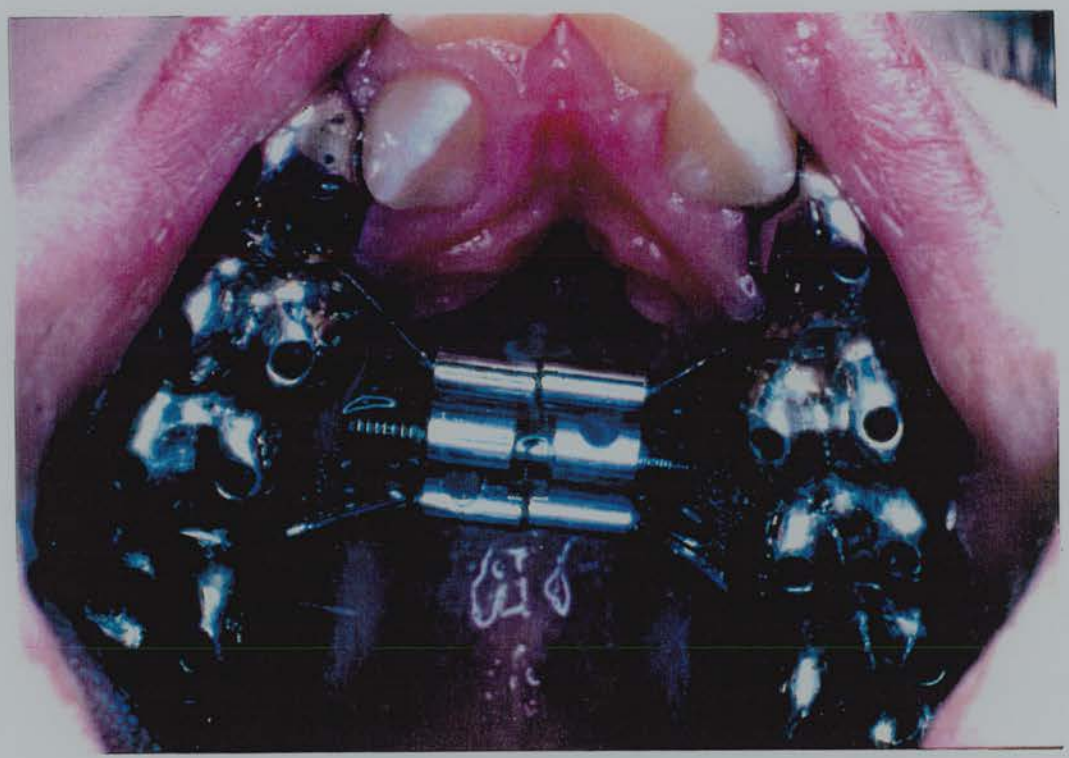


Fig. 12 RME appliance before activation

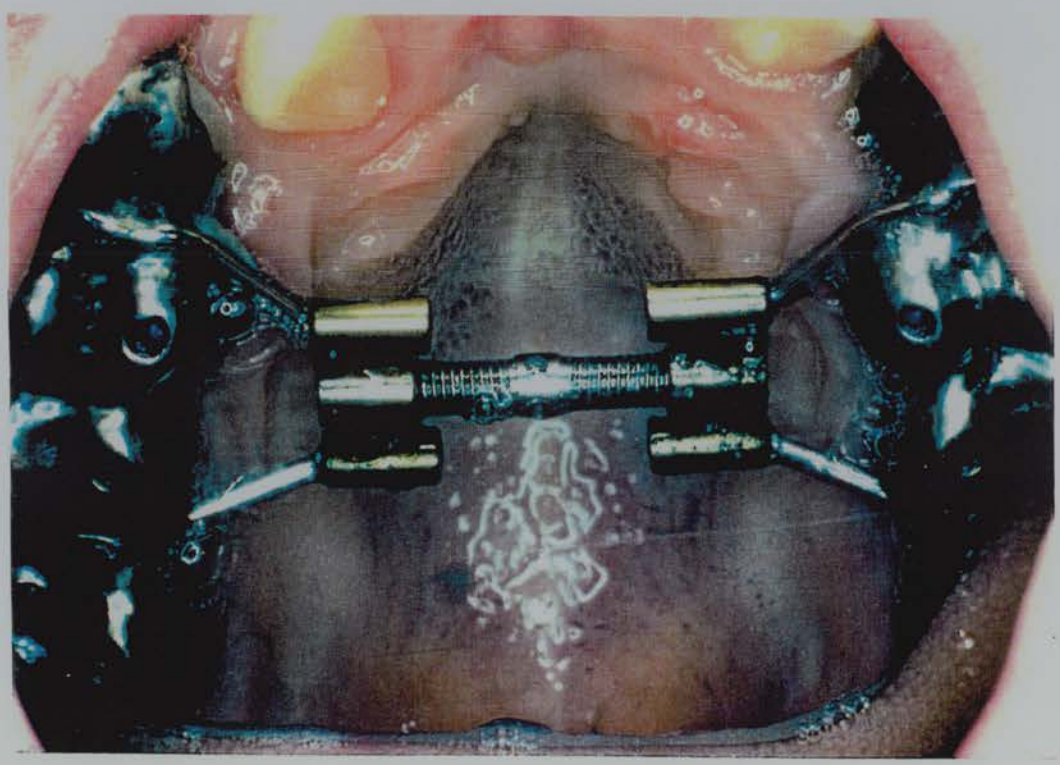


Fig. 13 RME appliance after activation

Fig. 14 RME appliance with utility (horizontal)

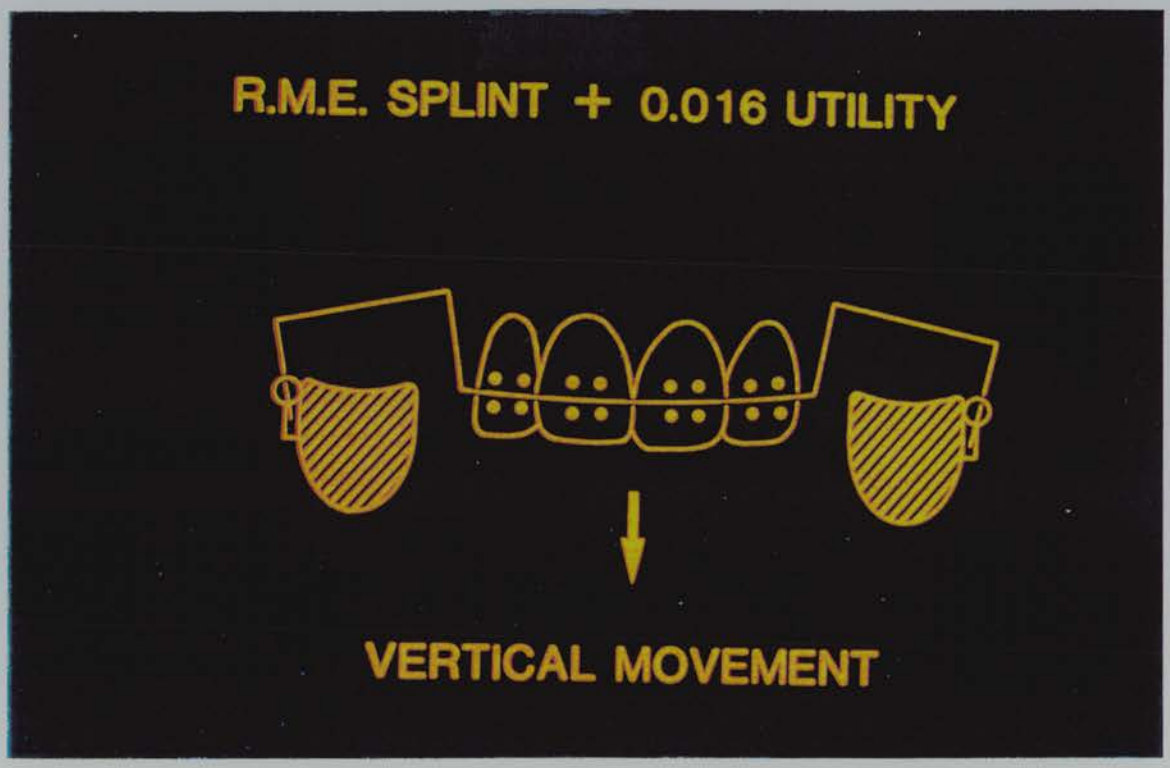


Fig. 15 RME appliance with utility (vertical)

Fig. 16 Intra oral view before RME

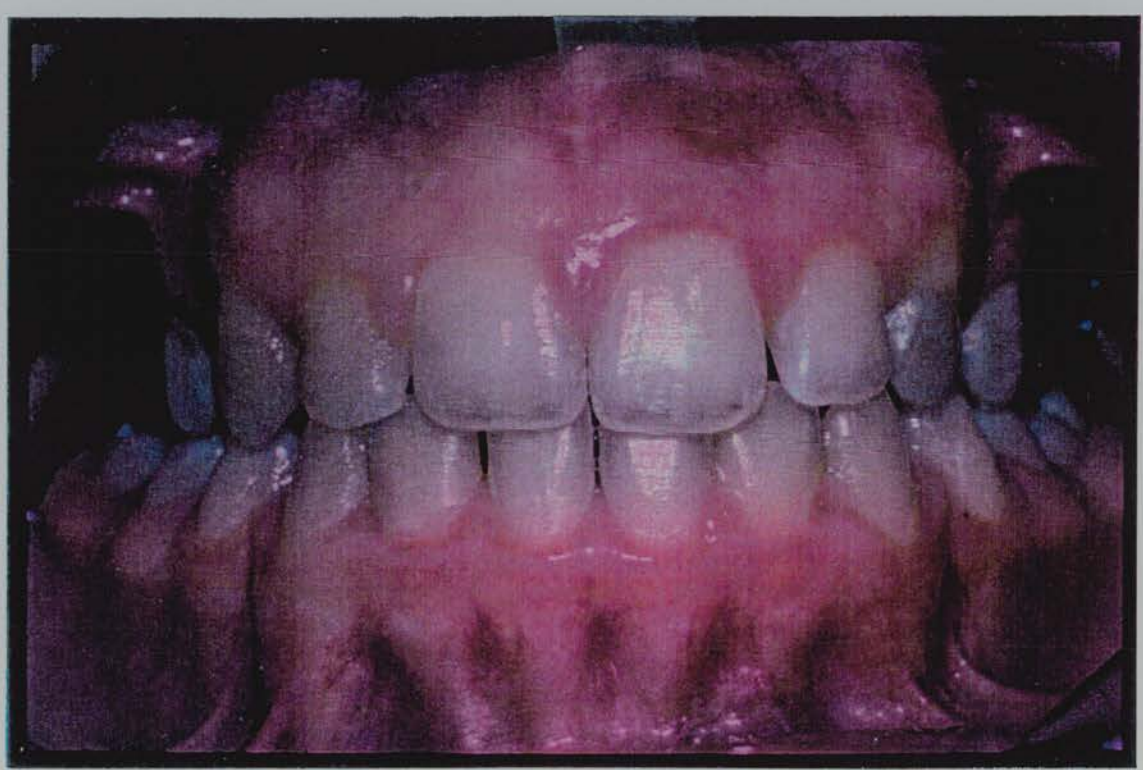


Fig. 17 Intra oral view after RME

incisal position gained (see Fig 15). This was coupled with a piggyback .012" superelastic Titanol to align the buccal segments, eventually working up through the archwires to a complete single upper arch in .018" x .025" stainless steel wire, the lower arch treatment being undertaken concurrently.

The fixed phase of treatment took in the region of one year, after which the bonds and bands were removed, the teeth cleaned and Hawley retainers fitted to both upper and lower arches to facilitate retention. These were left full-time in the region of six months, when a lower lingual fixed retainer was fitted to $\overline{321/123}$, the upper arch being retained night only by the Hawley for a further six months (see Figs 16, 17).

3.3 Measurement Procedures

Rhinomanometric Recordings

The rhinomanometer used (see Figs 18, 19) was a Mercury Electronics NR6 together with a BBC "B" Master Personal Computer printing onto an Epson FX80 Dot Matrix Printer. The software was modified for this study by the addition of a Rohrer chip to measure Laminar/Turbulent airflow (K1/K2).

The software was designed to calculate values of Nasal Airway Resistance at a pre-set pressure or pre-set flow threshold. The inspiration and expiration values were displayed on a VDU monitor for each cycle, and four such measurements were calculated, the mean values being shown on the screen. The VDU screen also displayed the pressure/flow curve from which the nasal airway resistance was calculated. This provided a visual feedback for the patient (see Fig 20).

The rhinomanometer was calibrated before each recording session utilising a dynamic pressure and flow calibration unit, which produced a flow that peaked at 150cc per second and a pressure that peaked at 500 pascal, which resembled the normal respiratory cycle and produced a sigmoid curve on the VDU. Threshold values for flow and pressure could be pre-set by adjustment to the rhinomanometer which facilitated easy and rapid calibration.

On arrival in the Department each patient whether from the control or anomaly sample, was administrated Otrivine (Xylometazoline Hydrochloride) as a spray to each nostril so that any untoward effect of the nasal cycle would be eliminated. The patient was then asked to sit quietly for five minutes without blowing his or her nose.

Rhinomanometric recordings were taken thirty minutes after the nasal spray administration. The rhinomanometer had been previously calibrated before the session for a flow of 150cc per second, peaking for a pressure at 500 Pascal, in accordance with the recommendations of the International Meeting on Rhinomanometry (Clement 1984). At pressure differences exceeding this standard

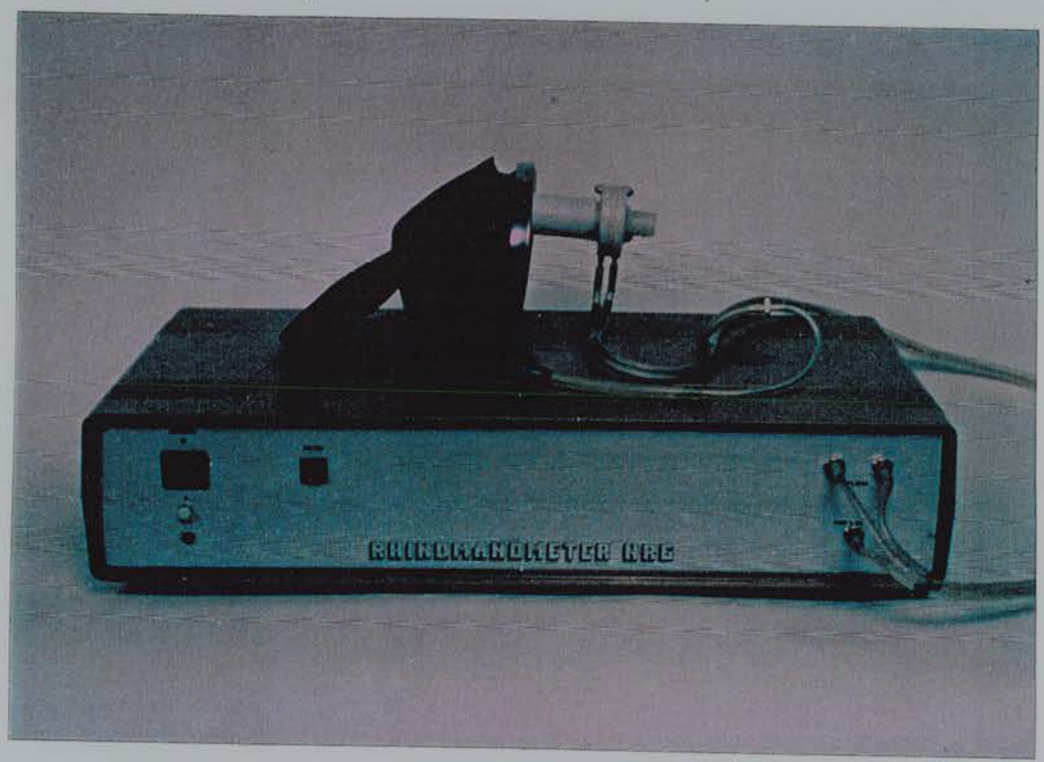


Fig. 18 Mercury NR6 Rhinomanometer

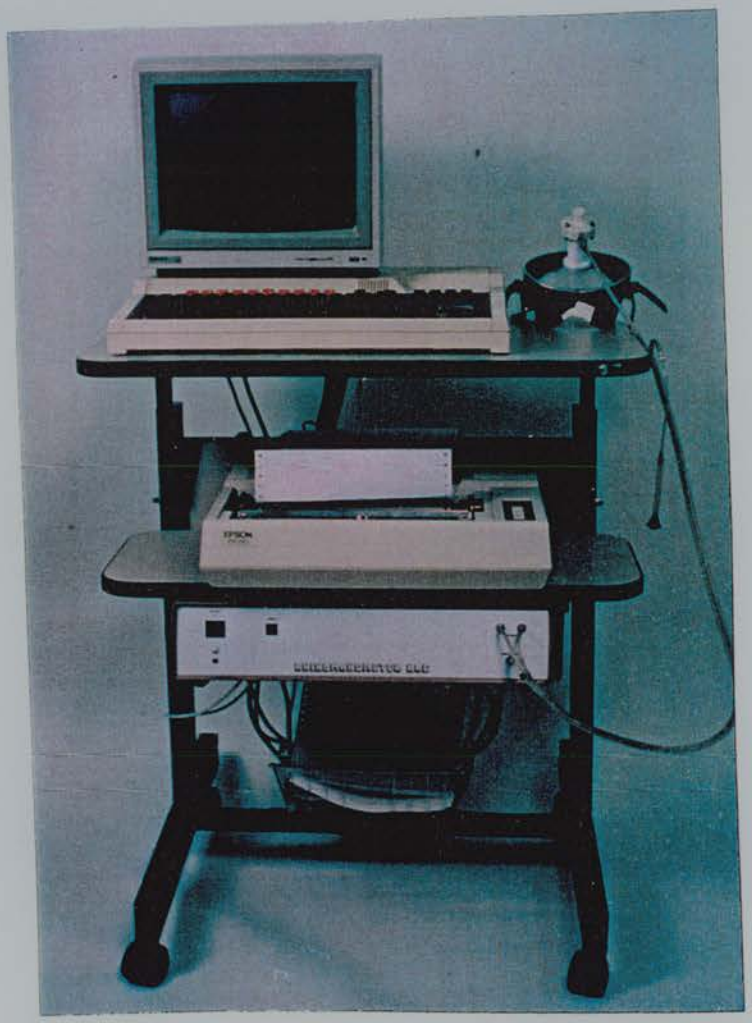
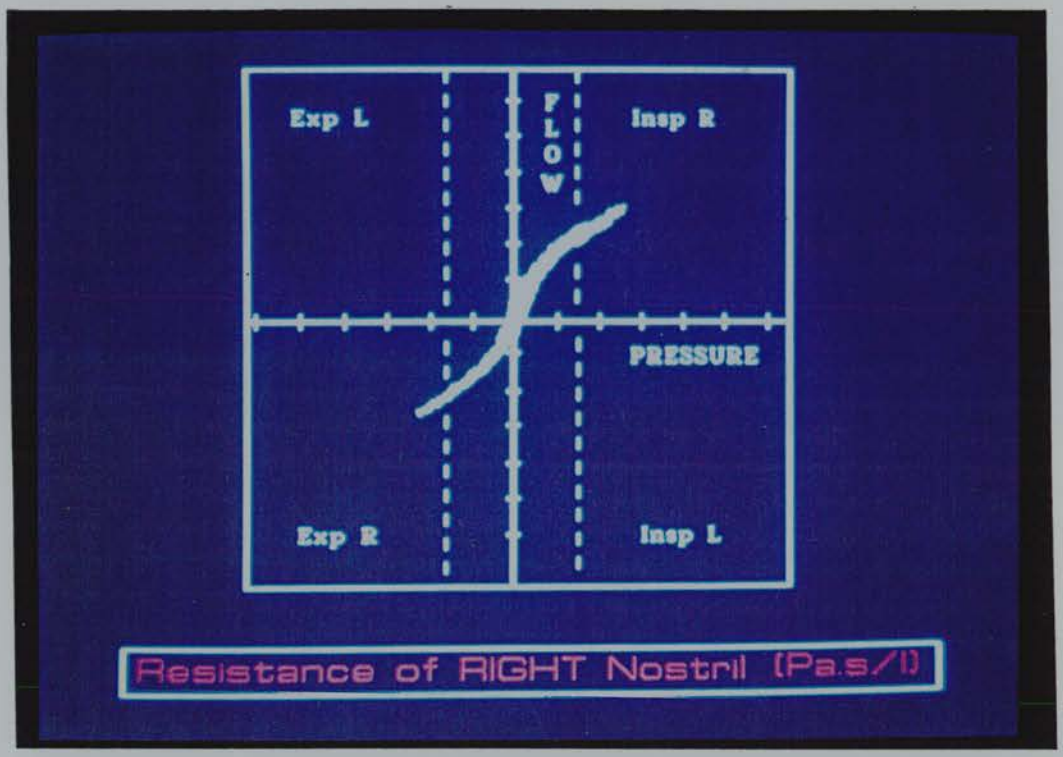


Fig. 19 NAR measurement apparatus



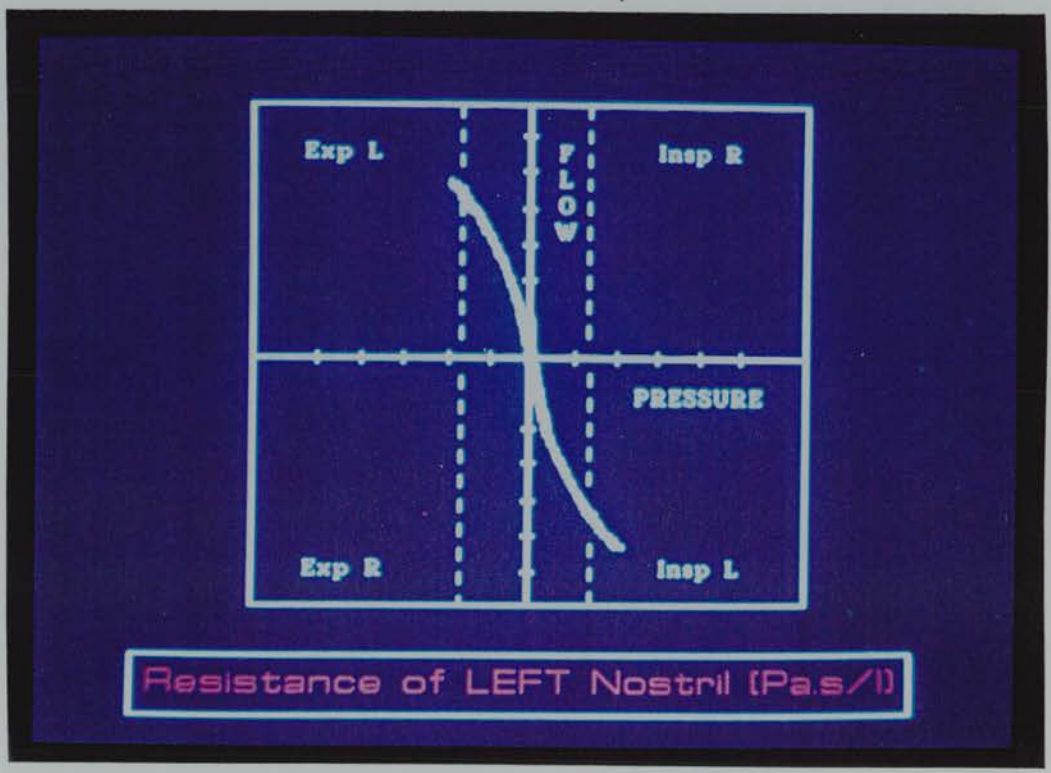


Fig. 20 Sigmoid curve on screen

threshold, the airflow and turbulence will increase and the resistance hence be higher. The laminar and turbulent component of a patient's nasal resistance are calculated separately utilising the Rohrer software chip. For each inspiration/expiration cycle a curve was fitted to all data points and the coefficients K1 (laminar) and K2 (turbulent) of the curve described by the Rohrer equation $\Delta p = K1x\dot{V}+K2x\dot{V}^2$, are calculated where Δp is the pressure drop and $\dot{V}$ the flow. The rhinomanometer was calibrated at the start of each recording session, and the measurements of nasal resistance were made unilaterally for the right and left sides by the anterior method, as well as bilaterally by the posterior method.

Anterior method - The resistance of each nasal half was recorded as described by Broms (1982) and Solow and Greve (1980) whereby a thin tube is fixed with tape to one nostril (see Fig 21) enabling the pressure behind the opposite nasal half to be recorded against the pressure outside the nostril. In both anterior and posterior nasal resistance measurements, a scuba diving mask as recommended by Hansen et al (1984) was utilised, to cover both nose and eyes (see Fig 23). Through a hole in the screen a connector for the pneumotachograph was fitted. Soft adhesive tape was utilised to seal the nostril, a hole being punched through the tape and a flange connector pushed through from the nasal side into a short retaining tube (see Fig 22), connecting to the pressure recording tube. This arrangement enabled the pressure recording fine bore tube to be easily connected and disconnected for recording purposes (see Fig 24). The nasal airway resistance for each half of the nose was recorded by sealing the pressure tube to the opposite nostril, the pressure recorded at the nasal aperture being equal to that behind the choaenae. Sixteen recordings for each component of the respiratory cycles, inspiration and expiration, were obtained. The adhesive tape was then removed from the nostril and applied to the opposite nostril, where a further sixteen recordings were gained. The mean values of the sixteen recordings were printed out to include K1 and K2. Rohrer fits the complete curve in a quadrant by least squares. The curve value for any Δp

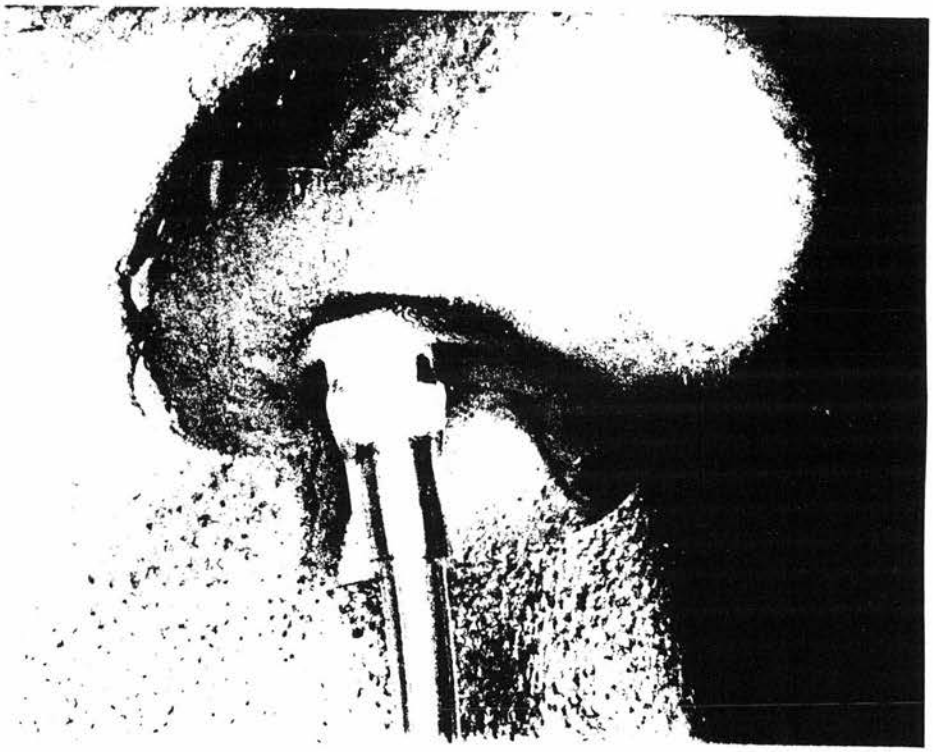


Fig. 21 Attachment of nasal tube to nostril

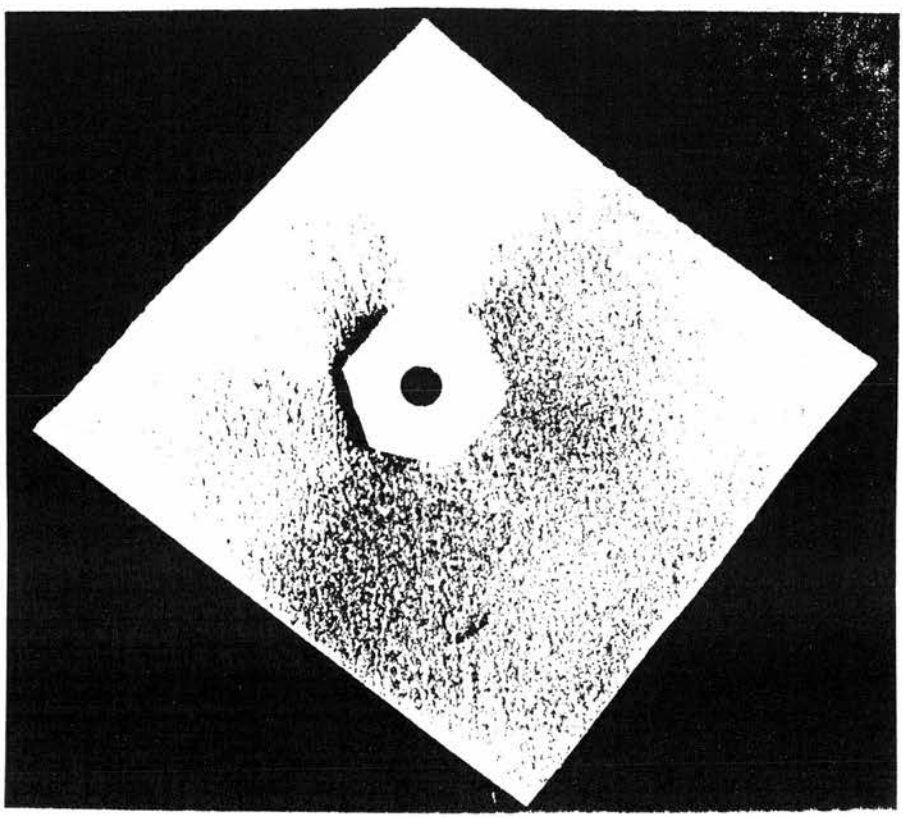


Fig. 22 Flange connector pushed through adhesive tape

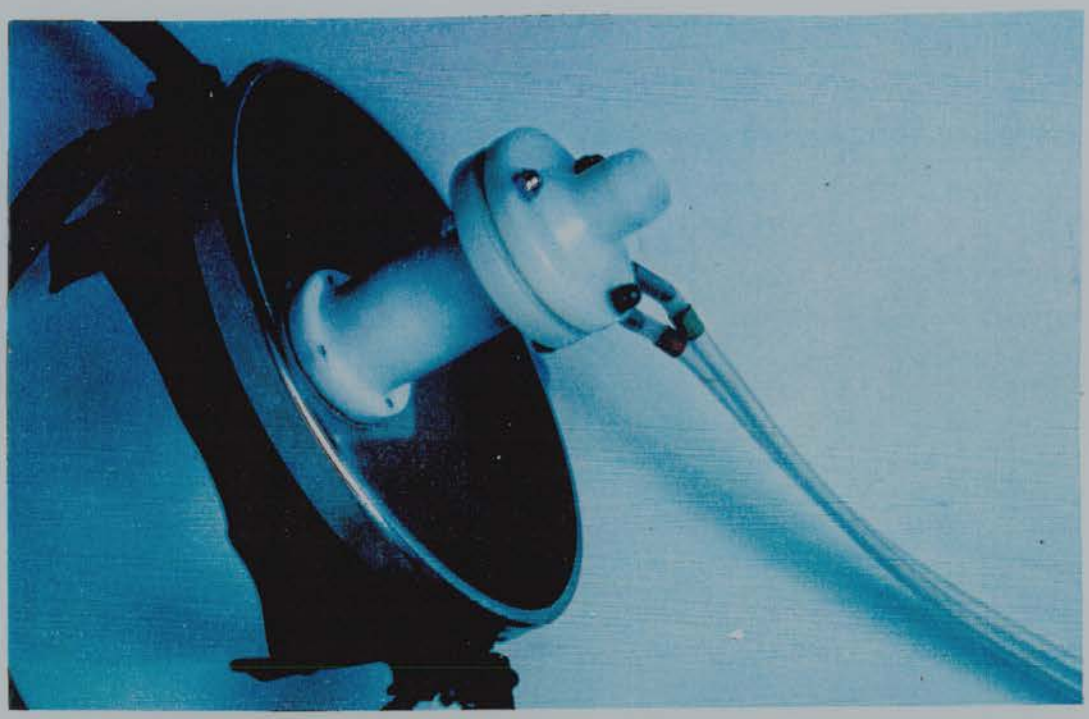


Fig. 23 Pneumotachograph and facemask

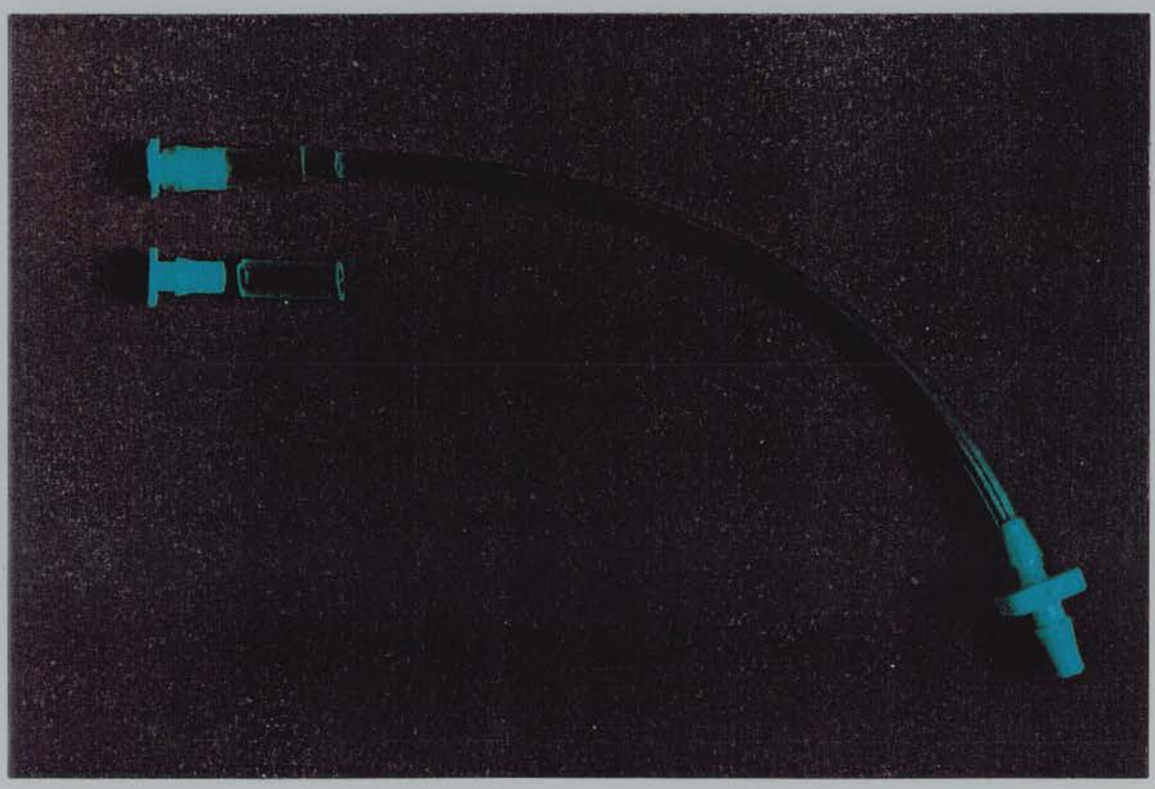


Fig. 24 Flange connector attachments

Fig. 25 Recording nasal airway resistance (posterior)

or $\dot{V}$ (eg 150Pa) can be derived from coefficients K1 and K2. It was possible to make the recordings with little or no discomfort to the patient.

Posterior method - As reported in the literature the taking of these measurements causes rather more problems. Hence, a large diameter (10cm long x 3mm internal diameter) polythene tube modified by an otoscope tip at the end to assist with correct soft palate position, was inserted into the oropharynx to record pharyngeal pressure. Visual feedback of the monitor trace was obtained for the patient as the recording was in progress. If the trace produced on the screen became erractic this was normally due to sealing of the nose by elevation of the palate producing oral airflow and increased pressure in the tube. Some practice was required to obtain accurate posterior measurements, the visual feedback being of prime importance. Again sixteen measurements of inspiration and expiration were obtained, they being sufficient to cross the threshold line, and the values printed out to include K1 and K2. It was found that most of the subjects could perform this measurement after some training (see Fig 25).

Method error testing was undertaken on 14 subjects (6 male, 8 female), at a standardised one hour after the initial testing.

Radiographs

Standardised lateral cephalometric radiographs were taken in a cephalostat incorporated into a Morito Pan X EC orthopantomogram, modified to produce cephalometric radiographs with the long side of the film in true vertical including the whole of the subject's head. (see Fig 26).

The subject was positioned in the natural head posture utilising an eyeline mirror as described by Solow and Tallgren (1971a) with the film placed at the right side of the face. The film focus distance was 176cm, the film median plane distance was 18cm, and the enlargement was 1.1%. The exposures were made at 80kv at 0.8 seconds using Trimatic "C" T16 blue-emitting cassettes with rare earth screen and Trimax 3M blue-based fast radiographic film of 24cm x 30cm. In order to enhance image

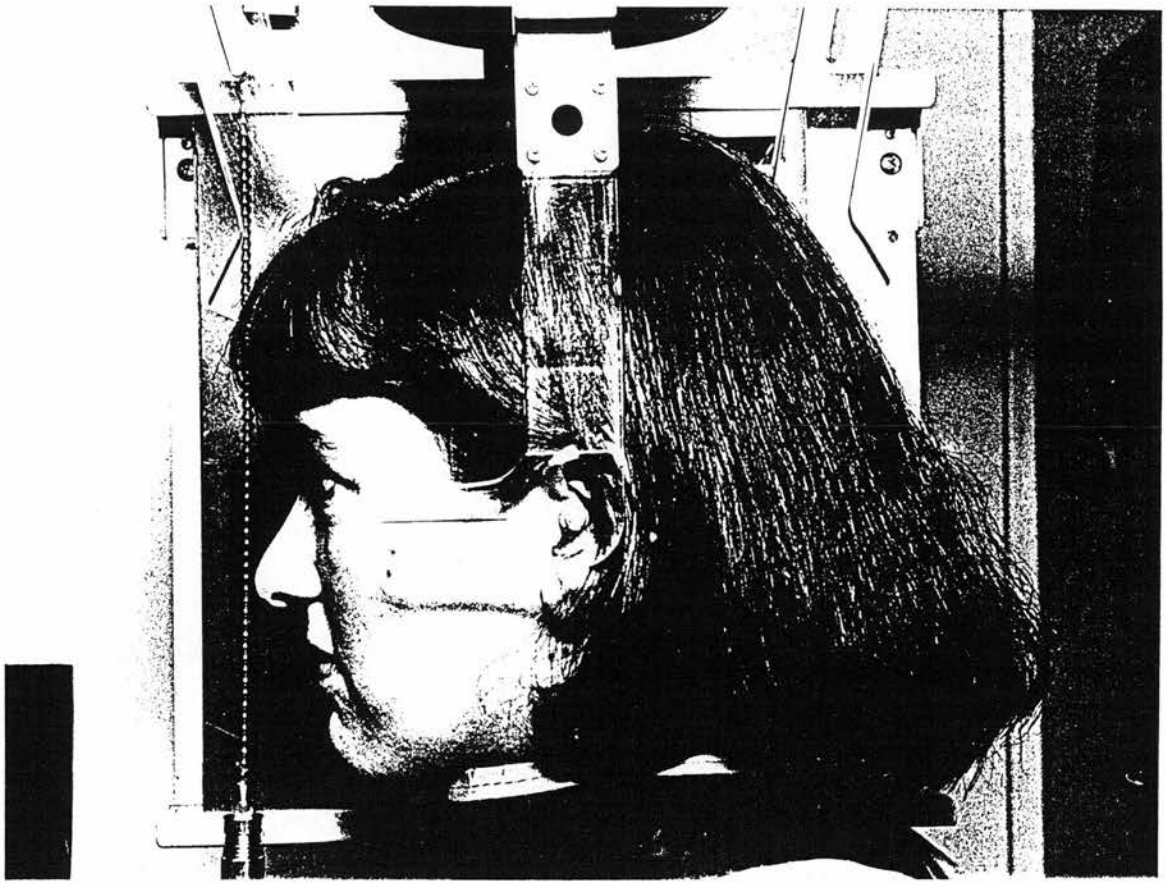


Fig. 26 Lateral skull cephalometrics in natural head position

quality, a grid was attached to the cassette. The grid had 70 absorbing strips per cm. A vertical plumb line 1.5mm in diameter was suspended at the occipital end of the filmholder in order to indicate a true vertical. A lead apron was worn by the patient to eliminate stray radiation to the body.

The posteroanterior radiographs - standardised PA radiographs were taken immediately after the lateral radiographs using the same equipment. (see Fig 27). The radiographs were taken in horizontal eye/ear line in order to avoid the projection of the par petrosa of the temporal bone. The film was exposed at 80kv for 1.3 seconds and 90mA.

The radiographs were digitised and analysed utilising software developed for the author, method error tests being undertaken as before and described in the method error section. The analysis was a 22-point analysis to show such changes in width that occur at the orbital level, the nasal cavity level, together with the maxillary and mandibular levels. In addition any changes in facial length were recorded, subdivided into nasal, maxillary and mandibular dimensions. The direction and dimensions of the movement of the nasal septum after rapid palatal expansion was noted, as were the changes in nasal dimension and maxillary dimension.

Digitiser

A GTCO digitiser coupled to a Digipad 5 screen was utilised to digitise the cephalometric and PA radiographs. Point and linearity reproducibility studies and testing of the digitiser were carried out as described in the Method Error section.

Study casts and photographs - Durable study models and working models for the RME splint were cast in stone plaster, and a registration wax bite was taken in every case. Clinical photographs were obtained at the same time to show profile, full face, three standard intraorals and a view of the palate.

Fig. 27 Postero-anterior cephalometrics

The cast splint for rapid palatal expansion was constructed in the Laboratory, fitted and activated as previously described. This took an average of 3.75 weeks. After the active part of the rapid maxillary expansion was completed, the rapid palatal expansion splint was removed, and the cephalometry, PA radiography, rhinomanometry, study models and photographs were repeated (Time 2). The splint was then refitted after the teeth had been cleaned and the patient left for some three months for the midline suture to reossify (Henrickson 1977). No method error retesting was necessary at this stage.

3.4 Measurements - Definitions and Calculations

The lateral cephalometric recordings were analysed utilising the GTCO digitiser on the Digipad 5, using software developed and written for previous studies. This gave compute-filed co-ordinate data for fifty seven reproducible points or cephalometric landmarks on the radiograph, delineating sixty four linear and angular variables. The fifty seven reproducible points were defined and numbered in the standard sequence then digitised.

i. Reference points used in the study (see Table 4, Figs 28-30)

ii. Radiographic cephalometric measurements (see Table 5)

iii. Reference lines used in the study (see Table 6, Figs 31, 32)

The postero-anterior cephalometric recordings were similarly analysed using the GTCO digitiser on the Digipad 5, but here the software used was developed specifically for this study. This gave compute-filed co-ordinate data for twenty two reproducible points on the radiographs, delineating twenty ~~six~~ linear variables.

As with the lateral cephalometric recordings, the twenty two reproducible points were traced and numbered in a standard sequence before digitising.

iv. Transverse reference point definition (see Table 7, Figs 33, 34)

v. Transverse linear measurements (see Table 8)

3.5 STATISTICAL PROCEDURES

Statistical methods were used to analyse the distribution, the changes that occurred, and the associations and correlations found.

The formulae utilised were:

1. arithmetical mean $\frac{\Sigma x}{N}$

2. standard deviation $\sqrt{\frac{\Sigma(x - \bar{x})^2}{N - 1}}$

3. variance $\frac{\Sigma(x - \bar{x})^2}{N - 1}$

4. standard error of mean $\frac{s}{\sqrt{N}}$

5. variation coefficient $\frac{s}{\bar{x}} \times 100$

6. variance ratio $\frac{s^2 \max}{s^2 \min}$

7. paired "t" test

i) $$\frac{|x_1 - \bar{x}_2|}{\sqrt{\frac{(N_1 - 1)\, s_1 + (N_2 - 1)s_2^2}{N_1 + N_2 - 2} \left(\frac{1}{(N_1 + N_2)}\right)}}$$

ii) $$\frac{|\bar{x}_1 - \bar{x}_2|}{\sqrt{\frac{S_1^2}{N_1} + \frac{S_2^2}{N^2}}}$$

8. method error (Hald 1960) $S(i) = \sqrt{\frac{\Sigma(x_1 - x_2)^2}{2N}}$

9. method error percentage $S(i)\,\% = \frac{[s(i)]}{s^2} \times 100$

10. correlation coefficient $\frac{\Sigma(x-\bar{x})\ (y-\bar{y})}{\sqrt{\Sigma(x-\bar{x})^2\ \Sigma(y-\bar{y})^2}}$

TABLE 4

REFERENCE POINTS USED IN THE STUDY

ad_3	The point on the most anterior part of the adenoidal mass the shortest distance from the posterior wall of the maxillary antrum.
ad_2	The intersection of a line, with the adenoidal mass, drawn from pm to the mid point of a line from s-ba.
ad_1	The intersection of a line, with the adenoidal area, drawn from pm to basion.
ai	The apex of the root of the lower central incisor.
ar	Articulare. The intersection between the external contour of the cranial base and the dorsal contour of the condylar head.
as	The apex of the root of the upper central incisor.
ba	Basion. The most postero-inferior point on the anterior margin of the foramen magnum.
cd	Condylion. The most supero-posterior point on the condylar head.
ct	Chin tangent point. The lower tangent point on the nose chin line.
cv2ap	The apex of the odontoid process of the second cervical vertebra.
cv2tg	The tangent point of OPT on the odontoid process of the second cervical vertebra.
cv2ip	The most postero-inferior point on the corpus of the second cervical vertebra.
cv4ip	The most postero-inferior point on the corpus of the fourth cervical vertebra.
ds	Dorsum nasi. The point located at the greatest convexity or concavity of the dorsum nasi.

ft	Frontal tangent point. The upper tangent point of the nose-frontal line.
gn	Gnathion. The most inferior point on the mandibular symphysis.
gn_S	Soft tissue gnathion. The soft tissue point overlying gn.
hy	Hyoideum. The most antero-superior point of the corpus of the hyoid bone.
id	Infradentale. The most antero-superior point on the lower alveolar margin.
ii	Incision inferius. The mid point of the incisal edge of the most prominent lower incisor.
int	Incision inferius. The mid point of the incisal edge of the most prominent lower central incisor.
ins	Incision occlusale. The projection of ii on OLS.
i_S	Incision superius. The mid point of the incisal edge of the most prominent upper central incisor.
Ii	Labrale inferius. The most prominent point on the prolabiun of the lower lip.
Int	Lower nasal tangent point. The upper tangent point of the nose chin line.
IIt	Lower lip tangent point. The upper tangent point of the tangent to the lower lip through sms.
Is	Labrale superius. The most prominent point on the prolabiun of the upper lip.
mlp	The posterior tangent point of ML.
mm_S	The most inferior point on the mesio-buccal cusp of the upper first permanent molar.
n	Nasion. The most anterior point of the fronto-nasal curvature.

n_s	Soft tissue nasion. The deepest point in the fronto-nasal curvature.
nst	Nasal septum tangent point. The anterior tangent point of the tangent to the nasal septum through sn.
o	Orbitale. The deepest point of the infra-orbital margin.
op	Opisthion. The most antero-inferior point on the posterior margin of foramen magnum.
p	Porion. The upper border of the bony external auditory meatus.
pg	Pogonion. The most anterior point on the mandibular symphysis.
pgn	Prognathion. The point on the mandibular symphysis farthest from cd.
pgn_s	Soft tissue prognathion. The soft tissue point overlying pgn.
pg_s	Soft tissue pogonion. The most prominent point on the chin.
pm	Pterygomaxillare. The intersection between the nasal floor and the posterior contour of the maxilla.
pr	Prosthion. The most antero-inferior point on the upper alveolar margin.
prn	Pronasale. The most prominent point on the apex of the nose.
rli	The lower tangent point of RL.
rls	The upper tangent point of RL.
s	Sella. The centre of the sella turcica.
sm	Supramentale. The most posterior point on the anterior contour of the lower alveolar process.
sme	Submentale. The deepest point in the submental neck curvature.
sm_s	Soft tissue supramentale. The deepest point in the mentolabial sulcus.
sn	Subnasale. The deepest point in the nasolabial curvature.
sp	Spinal point. The apex of the anterior nasal spine.

ss	Subspinale. The most posterior point on the anterior contour of the upper alveolar process.
ss_S	Soft tissue subspinale. The most dorsal point on the upper lip overlying ss.
sto	Stomion. The deepest point in the rima oris.
tu	Tuber. The most posterior point on the maxillary tuberosity.
tgo	The point of intersection between ML and RL.
unt	The upper nasal tangent point. The nasal tangent point of the nose frontal line.
vi	The lower point on the vertical line.
vs	The upper point on the vertical line.

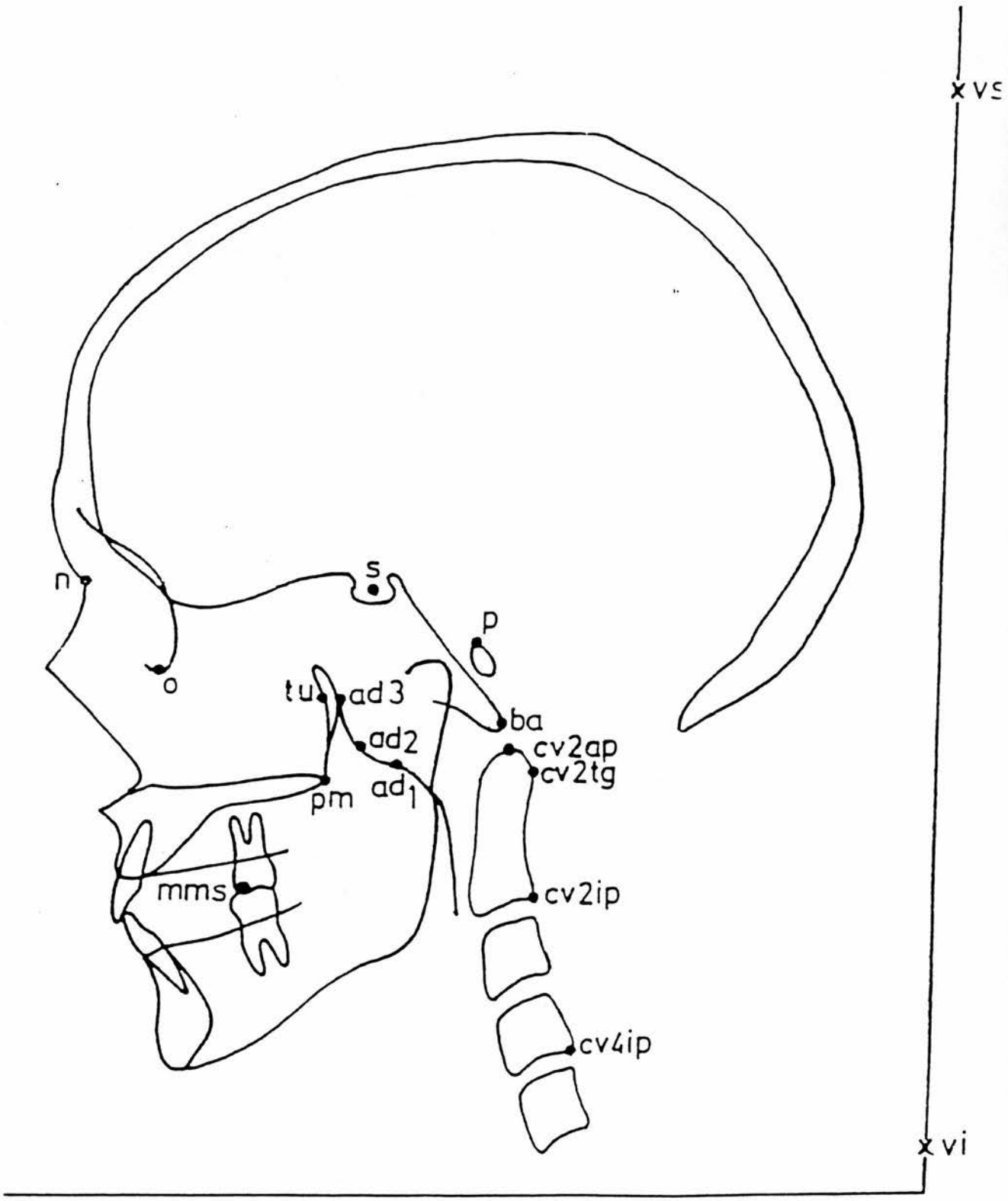


Fig. 28 Cephalometric reference points for head posture, airway and craniofacial morphology

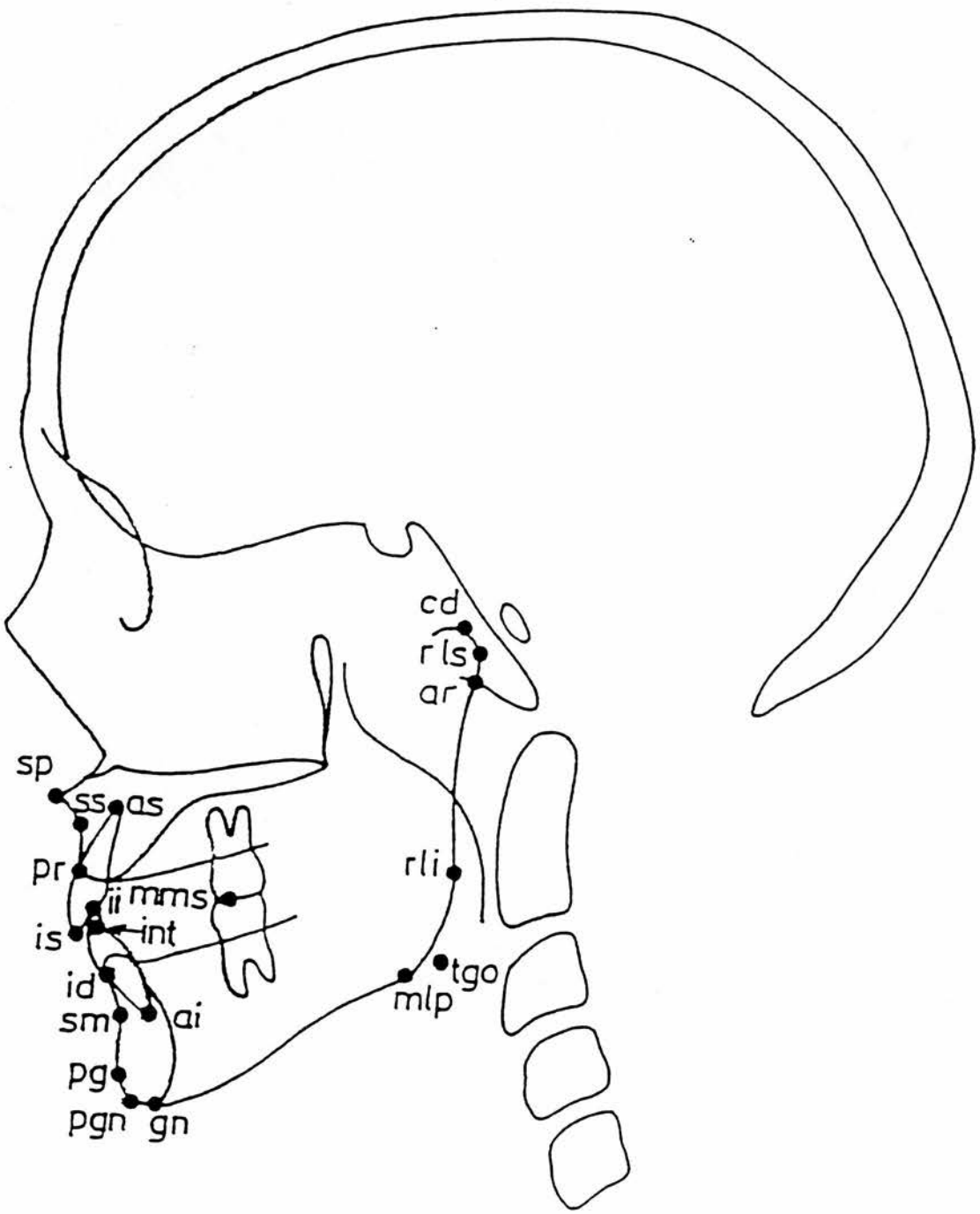


Fig. 29 Cephalometric reference points for mandibular and dento-alveolar structures

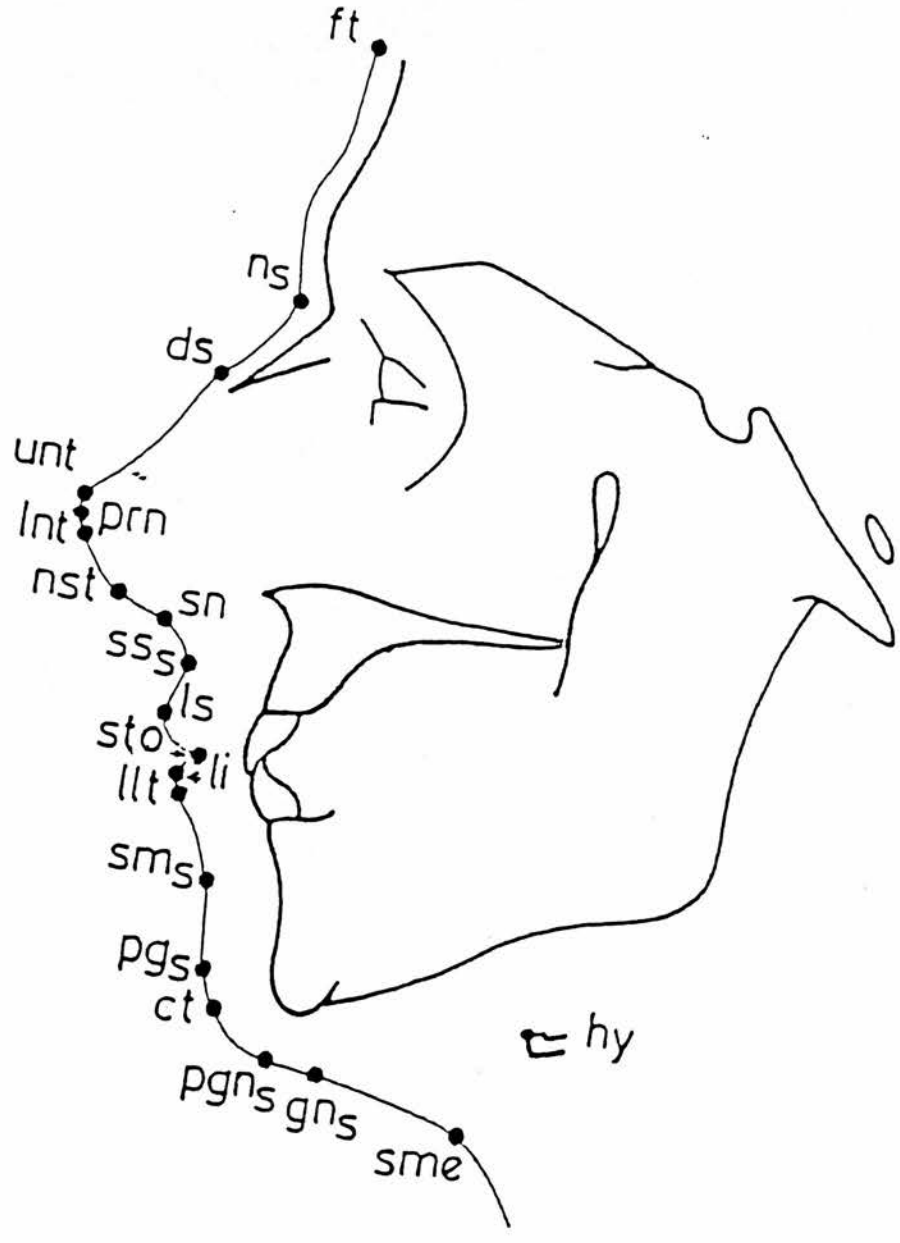


Fig. 30 Cephalometric reference points for soft tissue measurement

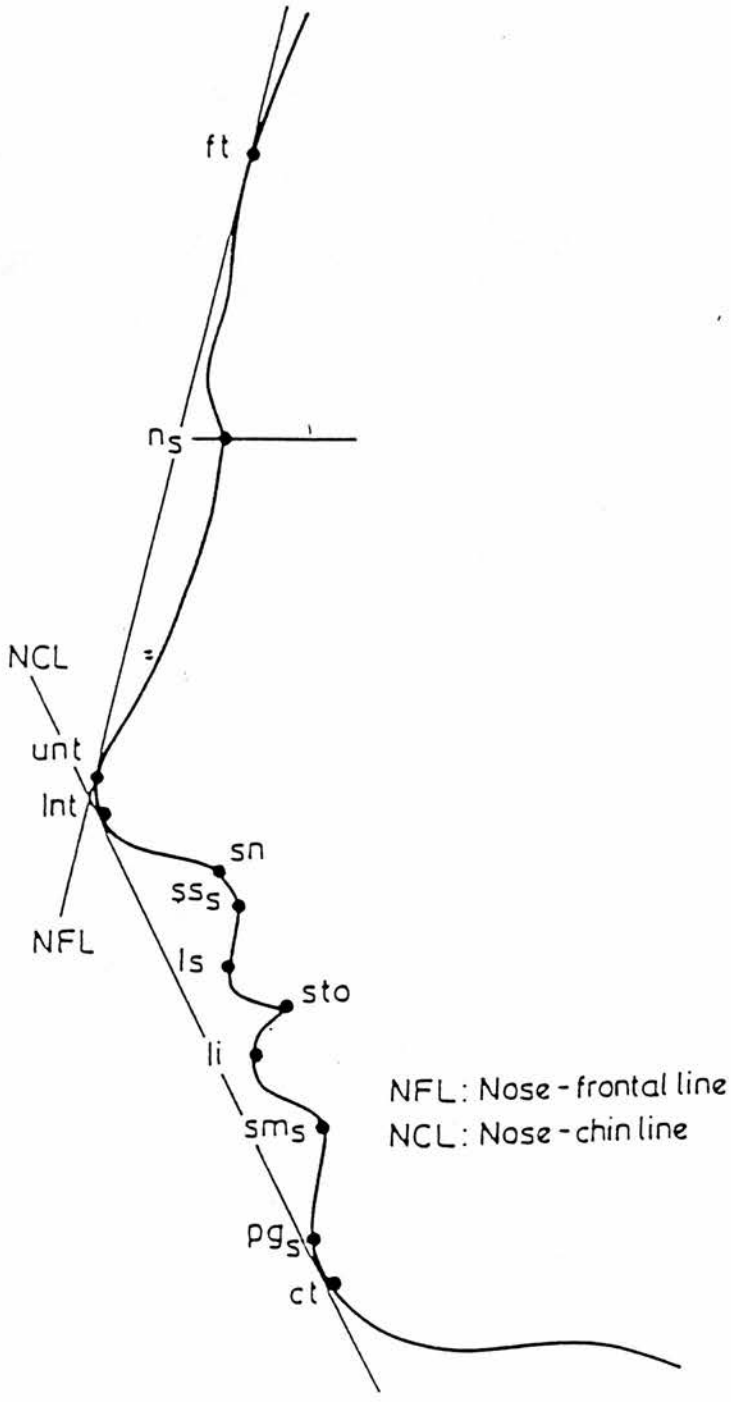


Fig. 31 Soft tissue reference planes

TABLE 5

RADIOGRAPHIC CEPHALOMETRIC MEASUREMENTS

a. **Linear dimensions**

1. n-s
2. n-sp
3. n-gn
4. s-ba
5. s-ar
6. s-pm
7. s-tgo
8. sp-gn
9. ar-tgo
10. sp-pm
11. ss-pm
12. pgn-cd
13. pg-tgo
14. sp-is
15. ii-gn

b. **Angular dimensions**

16. n-s-ba
17. n-s-ar
18. pm-s-ba
19. s-n-sp
20. s-n-ss
21. s-n-sm

22. s-n-pg
23. ss-n-sm
24. ss-n-pg
25. NSL/NL
26. NSL/ML
27. NL/ML
28. NSL/MBL
29. ML/RL

c. Dento-alveolar relations:

30. IL_s/NL
31. IL_i/ML
32. oj/(mm)
33. ob/(mm)

d. Head posture:

34. NSL/VER
35. NL/VER
36. NSL/OPT
37. NSL/CVT
38. NL/OPT
39. NL/CVT
40. OPT/HOR
41. CVT/HOR
42. FH/VER
43. FH/OPT

44. FH/CVT

e. Airway:

45. pm-ad_1

46. pm-ad_2

47. pm-ad_3

48. tu-ad_3

f. Soft tissue:

49. n_s-sn

50. n_s-prn

51. Int to n-ss

52. s-n_s-unt

53. sto to NL

54. s-n_s-ss

55. sn to Int-I_s

56. I_s to NCL

57. sto to ML

58. s-n_s-sm_s

59. sm_s to Ii-pg_s

60. Ii-NCL

61. ss_s-n_s-sm_s

62. sto to OL_s

63. s-n_s-pg_s

64. NFL/NCL

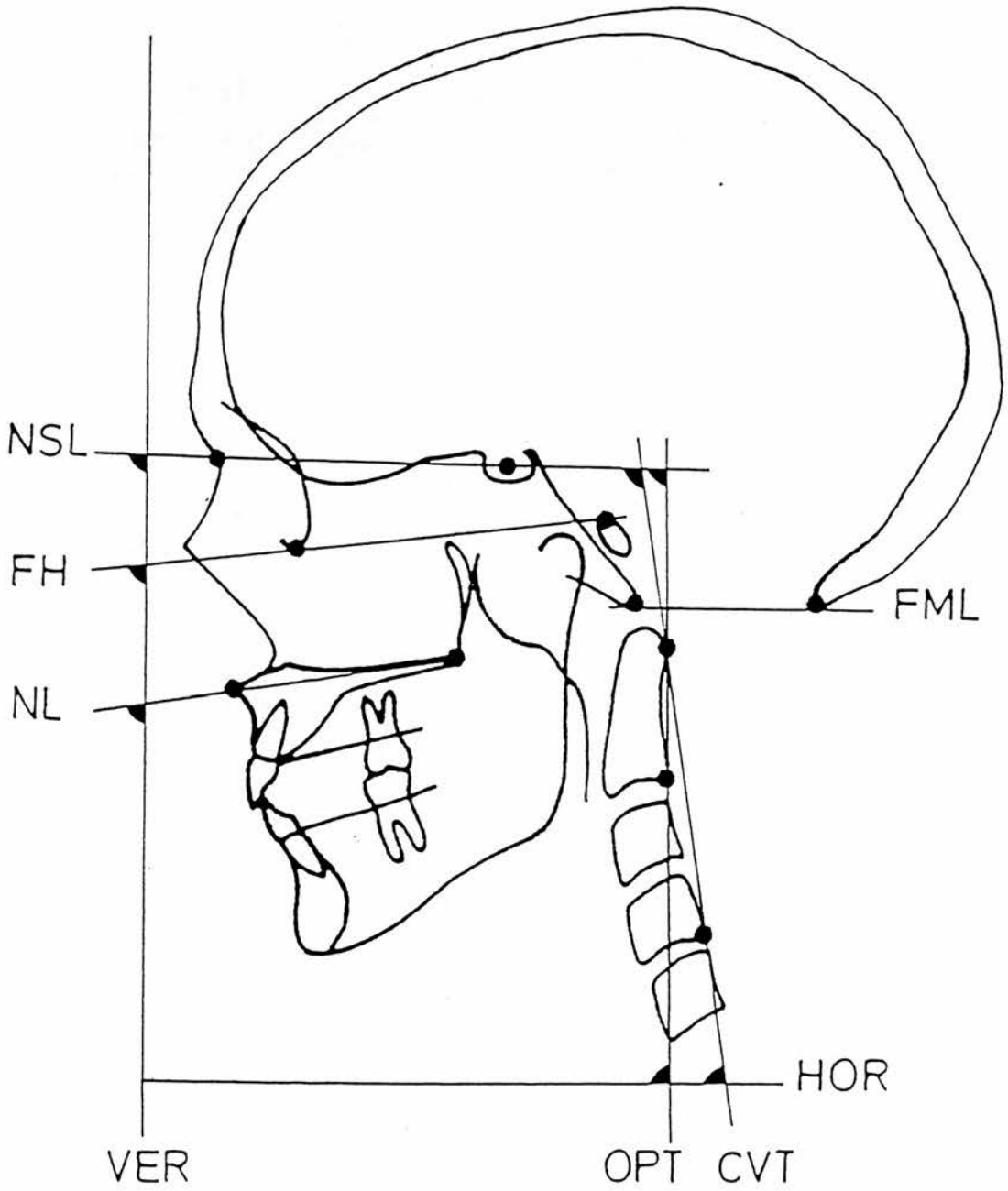


Fig. 32 Angular head posture variables

TABLE 6

REFERENCE LINES USED IN THE STUDY

CVT	Cervical vertebrae tangent. The posterior tangent to the odontoid process through cv4ip.
FH	Frankfort horizontal line. The line drawn from orbitale to porion.
HOR	True horizontal line. The line perpendicular to VER.
ob	Overbite. A linear measurement of the distance the upper central incisor overlaps the most prominent lower incisor measured from ii to int.
oj	Overjet. A linear dimension of the protrusion of the upper central incisor measured from is to int.
NCL	Soft tissue nose chin line. The line through Int and ct.
NFL	Soft tissue nose frontal line. The line through ft and un.
MBL	Mandibular base line. The line through pgn and cd.
ML	Mandibular line. The tangent to the lower border of the mandible through gn.
NL	Nasal line. The line through sp and pm.
NSL	Nasion-sella line. The line through n and s.
OPT	Odontoid process tangent. The posterior tangent to the odontoid process through cv2ip.
RL	Ramus line. The tangent to the posterior border of the mandible.
VER	True vertical line projected on the film.

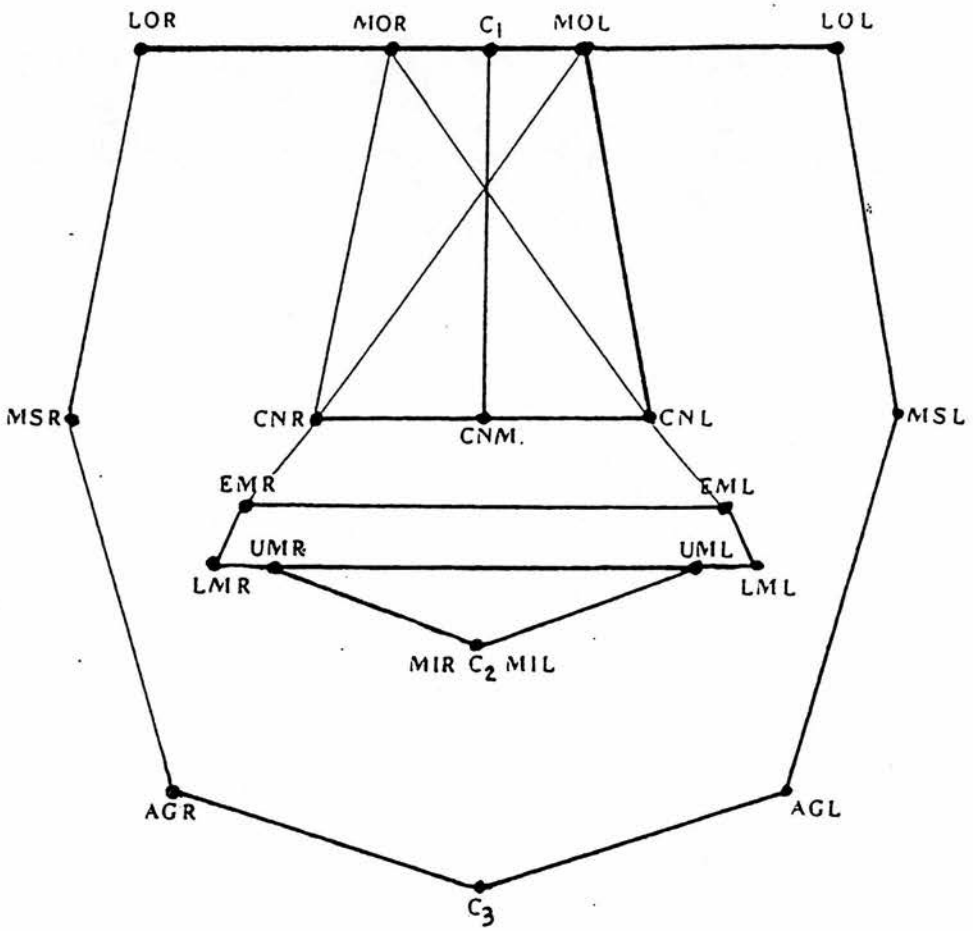


Fig. 33 Transverse cephalometric points

TABLE 7

TRANSVERSE POINT DEFINITION

Definitions of the points used -

LOR	The most lateral point on the right orbit
MOR	The most mesial point on the right orbit
C_1	The central point between MOR and MOL
MOL	The most mesial point on the left orbit
LOL	The most lateral point on the left orbit
MSR	The most lateral point on the right mastoid bone
CNR	The right cavum nasi
CNM	The point of the end of the nasal septum
CNL	The left cavum nasi
MSL	The most lateral point on the left mastoid bone
EMR	Ecto-maxillare right
EML	Ecto-maxillare left
LMR	The most lateral point on the lower right first molar
UMR	The most lateral point on the upper right first molar
MIR	The most mesial point on the upper right incisor
C_2	Central point between the two central incisors
MIL	The most mesial point on the upper left central incisor
UML	The most lateral point on the upper left first molar
LML	The most lateral point on the lower left first molar
AGR	The deepest point on the right antegonion notch
C_3	The centre point on the most inferior border of the mandible
AGL	The most lateral point on the left antegonion notch

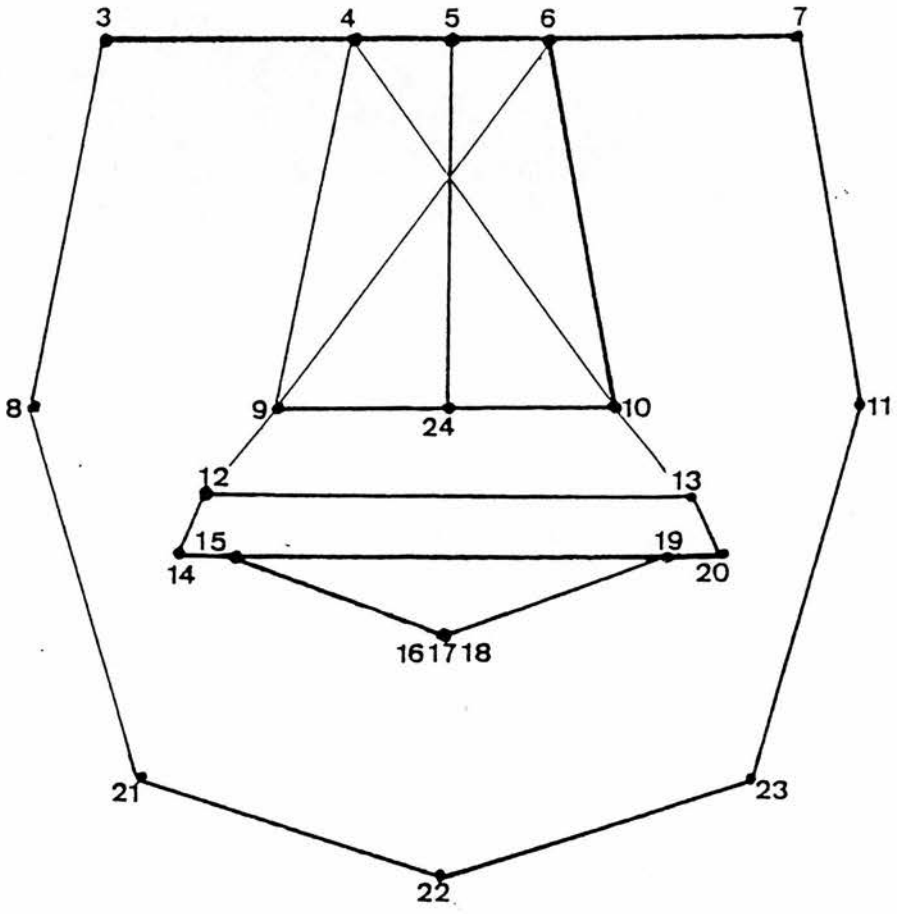


Fig. 34 Transverse cephalometric points in numerical sequence

TABLE 8

TRANSVERSE LINEAR MEASUREMENTS

at orbit level:

1. LOR-LOL
2. MOR-MOL
3. LOR-UMR
4. LOL-UML

at nasal level:

5. MSR-MSL

   CNR-CNL
6. CNR-CNM

   CNM-CNL
7. MOR-CNR
8. MOL-CNL

at maxillary level:

9. EMR-EML
10. UMR-UML
11. MIR-C_2
12. C_2-MIL
13. MIR-MIL
14. CNR-EMR
15. CNL-EML
16. EMR-UMR

17. EML-UML

18. UMR-MIR

19. MIL-UML

at mandibular level:

20. LMR-LML

21. AGR-AGL

proportionality:

22. NASDIM - 4-10, 6-9

23. MAXDIM - 4-13, 6-12

24. MANDDIM - 4-23, 6-21

The linear and angular measurements from both the cephalometric and PA measurements were analysed using an IBM 286 Computer and the in-house calculation package which had been rewritten for an IBM. The data was then downloaded onto the SPSS-X (Statistical Package for Social Studies) mainframe of Edinburgh University for final analysis.

In the statistical analysis, a probability $p<0.05$ or less was interpreted as statistically significant, $p<0.01$ rather more so and $p<0.001$ highly significant.

4.

METHOD ERRORS

4.1 RHINOMANOMETRIC METHOD ERRORS

To ascertain the rhinomanometric method error, fourteen subjects (6 male, 8 female) from the anomaly sample had duplicate airway assessments measured at the same recording session, with an interval of at least one hour between the initial and the duplicate measurements, under the same experimental conditions.

Measurements were made for right and left unilateral nasal resistance using the values obtained by the anterior method, as well as total nasal resistance using recordings obtained by the posterior method.

Results

The rhinomanometric method errors are given in Table 9.

There were no systematic differences shown at the $p < 0.05$ level. The method errors ranged between 14.79 for the posterior expiration and 37.91 for the anterior inspiration (left). These values compared well with results of previous studies (see Table 10).

The error percentage ranged between 3.57% for the anterior expiration (right) and 11.76% for the anterior inspiration (right).

TABLE 9

METHOD ERRORS - NASAL AIRWAY RESISTANCE

DUPLICATE DETERMINATION OF NRR FOR POSTERIOR AND ANTERIOR MEASUREMENTS

(Pascal/cc/sec x 10^3)

Variable	N	Min.	Max.	Mean Diff.	Standard error of Mean Difference	P	S(i)	S(i)%
ANT(L)								
INSP	14	-202	256	14.10	11.39	ns	37.91	10.13
EXP	14	- 78	125	18.02	11.70	ns	38.48	9.50
ANT (R)								
INSP	14	-146	82	19.80	10.92	ns	35.90	11.76
EXP	14	- 45	49	2.40	4.55	ns	18.77	3.57
POST								
INSP	10	- 85	73	16.40	8.73	ns	27.62	9.32
EXP	10	- 48	13	16.10	4.71	ns	14.79	9.83

TABLE 10

METHOD ERRORS - NASAL AIRWAY RESISTANCE

COMPARISON OF S(i) WITH A PREVIOUS STUDY

Variable	Current	Solow and Sandham 1988
ANT(L)		
INSP	37.91	33.3
EXP	38.48	24.3
ANT (R)		
INSP	35.90	41.5
EXP	18.77	32.7
POST		
INSP	27.62	18.9
EXP	14.79	13.6

4.2 POSTERO-ANTERIOR RADIOGRAPHS

All the following cephalometric procedures relating to postero-anterior and lateral radiographs are based on data recorded on a GTCO digitiser coupled to a Digipad 5 Screen. The errors that occur in this procedure are two-fold; the first relates to errors of point identification, the second to errors within the recording apparatus.

There have been few studies relating to the precision of digitisers (McWilliam and Welander 1978; Eriksen and Solow 1991). It is obviously important that the linear validity of the digitising pad is checked, otherwise any given line will be recorded as having different lengths depending on where it is placed on the digitising pad. The accuracy of the digitising system used in this study was specified by the manufacturer as 0.1mm, and the resolution as 0.025mm. The accuracy of the digitiser was checked by the repeated recording of a set of points spread over the digitising area and the method errors found to be 0.08mm for the "x" axis and 0.14mm for the "y" axis.

Eriksen and Solow (1991) addressed the problems that digitisers may suffer from a further source of error, that of linearity due to the fact that electromagnetic fields are not homogenous over the entire surface of the screen due to the physical construction and location of the components of the system. They developed algorithms to assess and display the characteristics of digitisers, and suggested that inhomogenous fields can be electronically corrected by using the digitiser control unit.

It is generally accepted that direct digitising of the anatomical reference points from the radiographs is more reproducible than digitising from tracings (Richardson 1966, Houston 1982, Cohen 1984 and Sandham 1988) so direct digitising was utilised throughout the study.

Twenty postero-anterior films from the control sample had points defined, and digitised utilising the computer software developed for this study.

Four weeks later the process was repeated to enable comparisons to be made between the two sets of readings.

Results

The method errors for the P/A films are presented in Table 11.

No systematic differences were found, ($p > 0.05$). The method errors varied between 0.12 mm for MIR-C_2 and 0.51 mm for MSR-MSL.

The percentage errors varied between 1.3% for CNR-CNL and 9.3% for MSR-MSL.

TABLE 11

METHOD ERRORS P.A. RADIOGRAPHS
DISTRIBUTION OF THE DIFFERENCES BETWEEN DUPLICATE MEASUREMENTS

CL Sample

Variable	N	Min.	Max.	Mean Diff.	Standard error of Mean Difference	P	S(i)	S(i)%
CNR-CNM	20	-0.5	0.7	0.27	0.0440	ns	0.24	2.2
CNM-CNL	20	-1.3	1.0	0.37	0.0850	ns	0.37	5.1
MOR-MOL	20	-0.8	0.9	0.39	0.0670	ns	0.35	1.8
MSR-MSL	20	-1.0	1.5	0.51	0.1150	ns	0.51	9.3
CNR-CNL	20	-0.6	0.9	0.51	0.1180	ns	0.25	1.3
EMR-EML	20	-0.2	0.7	0.26	0.0430	ns	0.23	5.1
UMR-UML	20	-0.6	0.8	0.35	0.0366	ns	0.27	5.2
LMR-LML	20	-0.7	0.4	0.27	0.0384	ns	0.22	2.7
AGR-AGL	20	-0.7	1.5	0.44	0.0974	ns	0.43	7.6
MIR-MIL	20	-0.4	0.7	0.16	0.0456	ns	0.18	2.2
MOR-CNR	20	-0.9	1.1	0.31	0.0624	ns	0.29	8.8
MOL-CNL	20	-0.5	1.0	0.42	0.0555	ns	0.34	8.4
CNR-EMR	20	-0.5	0.7	0.25	0.0438	ns	0.22	6.2
CNL-EML	20	-1.0	1.1	0.35	0.0534	ns	0.26	8.7
EMR-UMR	20	-0.8	1.3	0.45	0.0783	ns	0.40	2.0
EML-UML	20	-0.5	0.6	0.21	0.0355	ns	0.19	4.2
UML-MIR	20	-0.8	1.3	0.38	0.0523	ns	0.31	6.6
MIL-UML	20	-0.8	1.1	0.35	0.0738	ns	0.33	7.5
LOR-UMR	20	-0.6	0.3	0.47	0.0941	ns	0.44	4.9
LOL-UML	20	-1.2	1.1	0.54	0.0883	ns	0.47	6.1
MIR-C_2	20	-0.4	0.5	0.09	0.0328	ns	0.12	2.9
C_2-MIL	20	-0.7	0.4	0.13	0.0428	ns	0.14	3.9
NASDIM	20	-0.5	0.7	0.43	0.0664	ns	0.37	3.1
MAXDIM	20	-0.5	0.7	0.37	0.0792	ns	0.36	5.4
MANDDIM	20	-0.6	1.1	0.37	0.0821	ns	0.36	6.8

4.3 HEAD POSTURE ANALYSIS

In order to assess the error of head posture measurement, ten subjects (6 female, 4 male) aged between 10 and 15 years had duplicate lateral skull radiographs taken. All these subjects were from the anomaly sample.

These duplicate radiographs were exposed only if the original was deemed unsatisfactory due to missed cranial structures, overexposure of soft tissue or incorrect bite registration. The elapsed time between the original and duplicate radiographs was a minimum of one hour, and any duplicates were requested only after scrutiny of the originals by the author. Hence, any unnecessary exposure to ionising radiation was avoided.

The same Superintendent Radiographer exposed both the original and the duplicate films utilising the same cephalometric machine and the same type and manufacture of film on each occasion.

The sample was accumulated over a period of six months. The method for positioning the head in its natural position was that developed by Solow and Tallgren (1971), as described in the Methodology section.

The relevant cephalometric points on the original and duplicate radiographs were digitised utilising computer software developed specifically for this project.

The variables recorded are from Table 5, ie

- NSL/VER
- NSL/OPT
- NSL/CVT
- OPT/HOR
- CVT/HOR
- OPT/CVT

Results

The results of the method error study for head posture are given in Table 12.

They show no systematic difference between the two series, ($p > 0.05$). The method error ranged between 1.08 degrees for OPT/CVT to 2.23 degrees for NSL/CVT. These results are comparable with those of previous studies (see Table 13).

The error percentages ranged from 2.3% for NSL/CVT to 12.4% for NSL/VER and OPT/HOR.

TABLE 12

METHOD ERRORS - POSTURAL ANGLES

DISTRIBUTION OF DIFFERENCES BETWEEN FIRST AND SECOND RECORDING OF POSTURAL ANGLES

Anomaly Sample

Variable	N	Min.	Max.	Mean Diff.	Standard error of Mean Difference	P	S(i)	S(i)%
NSL/VER	10	-3.6	5.0	0.13	0.46	ns	1.61	12.4
NSL/OPT	10	-4.9	4.6	0.33	0.54	ns	1.73	10.3
NSL/CVT	10	-6.7	5.2	0.07	0.74	ns	2.23	2.3
OPT/HOR	10	-3.1	2.8	0.26	0.35	ns	1.24	12.4
CVT/HOR	10	-7.0	2.8	0.01	0.61	ns	1.94	10.1
OPT/CVT	10	-1.7	3.9	0.26	0.35	ns	1.08	9.4

TABLE 13

METHOD ERRORS - POSTURAL ANGLES

COMPARISON OF S(i) WITH PREVIOUS STUDIES

	SANDHAM 1988	SOLOW & SIERSBAEK-NIELSEN 1982	PRESENT
NSL/VER	3.20	2.25	1.61
NSL/OPT	2.56	3.39	1.73
NSL/CVT	2.44	3.37	2.23
OPT/HOR	3.84	3.07	1.24
CVT/HOR	3.25	3.09	1.94
OPT/CVT	0.97	0.90	1.08

4.4 CEPHALOMETRIC VARIABLES

For assessment of method errors, twenty lateral films from the control sample had cephalometric points defined then digitised. Four weeks later this procedure was repeated to enable comparison of the measurements obtained for the same linear and angular variables.

The differences between the measurements on the initial and secondary tracings were calculated and a statistical analysis performed.

Results

The method errors are reported in Table 14.

No significant differences ($p > 0.05$) were found. The method errors between the first and second set of records for angular measurements ranged between 0.31 degrees for ss-n-pg to 1.53 degrees for IL_S/NL. The method error for linear measurements varied between 0.33 mm for Int to n-ss and 1.05 mm for n_S-prn.

The percentage error for angular values ranged between 4.37% for NSL/ML and 6.58% for n-s-ar. The percentage error for linear values ranged between 2.08% for sp-is and 8.62% for n-s.

TABLE 14

METHOD ERRORS - CEPHALOMETRICS
DISTRIBUTION OF THE DIFFERENCES BETWEEN THE DUPLICATE MEASUREMENTS

CL Sample

Variable	N	Min.	Max.	Mean Diff.	Standard error of Mean Difference	P	S(i)	S(i)%
n-s	20	-0.40	1.10	0.44	0.153	ns	0.449	8.62
n-sp	20	-1.10	0.60	-0.18	0.195	ns	0.453	5.40
n-gn	20	-2.10	0.90	-0.11	0.339	ns	0.749	4.87
s-ba	20	-1.60	1.40	-0.13	0.272	ns	0.599	4.67
s-ar	20	-1.40	1.10	-0.15	0.296	ns	0.637	4.63
s-pm	20	-2.10	2.50	0.16	0.437	ns	0.933	4.56
s-tg	20	-0.90	1.10	0.24	0.187	ns	0.431	5.32
sp-gn	20	0.00	1.00	0.10	0.187	ns	0.446	4.40
ar-tgo	20	-0.90	1.00	0.11	0.213	ns	0.458	4.64
sp-pm	20	-1.80	2.80	0.49	0.393	ns	0.675	3.22
ss-pm	20	-1.20	2.30	0.15	0.356	ns	0.673	3.57
pgn-cd	20	-2.10	0.70	-0.33	0.281	ns	0.639	5.18
pg-tgo	20	-1.00	1.40	0.23	0.241	ns	0.552	5.25
sp-is	20	-1.10	1.10	0.14	0.199	ns	0.434	2.08
ii-gn	20	-1.10	0.90	-0.17	0.207	ns	0.455	4.83

TABLE 14 (cont)

DISTRIBUTION OF THE DIFFERENCES BETWEEN THE DUPLICATE MEASUREMENTS

CL Sample

Variable	N	Min.	Max.	Mean Diff.	Standard error of Mean Difference	P	S(i)	S(i)%
n-s-ba	20	-2.80	1.10	-0.57	0.444	ns	1.024	5.32
n-s-ar	20	-3.20	0.60	-0.99	0.484	ns	1.242	6.58
pm-s-ba	20	-3.00	4.00	-0.35	0.632	ns	1.360	4.63
s-n-sp	20	-1.40	2.10	0.31	0.359	ns	0.822	5.23
s-n-ss	20	-1.70	1.00	-0.06	0.253	ns	0.539	4.54
s-n-sm	20	-0.70	1.40	0.21	0.197	ns	0.427	4.69
s-n-pg	20	-0.80	1.40	0.19	0.220	ns	0.486	4.87
ss-n-sm	20	-1.20	0.70	-0.21	0.159	ns	0.365	5.36
ss-n-pg	20	-1.00	0.60	-0.21	0.130	ns	0.314	5.80
NSL/NL	20	-3.10	1.00	-0.45	0.433	ns	0.973	5.04
NSL/ML	20	-0.90	0.80	-0.13	0.207	ns	0.433	4.37
NL/ML	20	-1.30	3.90	0.30	0.508	ns	1.099	4.67
NSL/MBL	20	-1.40	0.90	0.31	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	2.20	-0.19	0.722	ns	1.530	5.58
ILi/ML	20	-2.30	3.80	0.63	0.662	ns	1.473	4.49
oj	20	-0.80	0.90	-0.01	0.168	ns	0.357	4.95
ob	20	-1.20	1.10	0.00	0.210	ns	0.445	4.50
NSL/VER	20	-2.20	1.80	-0.37	0.367	ns	0.821	4.50
								5.00

TABLE 14 (cont)

DISTRIBUTION OF THE DIFFERENCES BETWEEN THE DUPLICATE MEASUREMENTS

CL Sample

Variable	N	Min.	Max.	Mean Diff.	Standard error of Mean Difference	P	S(i)	S(i)%
NL/VER	20	-2.30	1.20	-0.52	0.369	ns	0.529	5.54
NSL/OPT	20	-3.90	2.90	0.07	0.563	ns	1.194	4.50
NSL/CVT	20	-2.00	1.60	-0.03	0.347	ns	0.737	4.50
NL/OPT	20	-2.00	3.20	0.51	0.505	ns	1.130	5.00
NL/CVT	20	-1.50	3.70	0.44	0.471	ns	1.047	4.93
OPT/HOR	20	-2.40	1.70	-0.43	0.445	ns	1.128	6.43
CVT/HOR	20	-1.60	1.00	-0.36	0.274	ns	0.634	5.37
FH/VER	20	-1.40	1.70	0.10	0.345	ns	0.736	4.54
FH/OPT	20	-2.50	3.00	0.53	0.463	ns	1.053	5.18
FH/CVT	20	-0.80	1.80	0.43	0.287	ns	0.709	6.12
pm-ad_1	20	-2.20	1.80	0.02	0.380	ns	0.806	4.49
pm-ad_2	20	-2.50	1.90	0.27	0.467	ns	1.009	4.66
pm-ad_3	20	-1.90	2.30	0.21	0.406	ns	0.884	4.75
tu-ad_3	20	-0.90	1.40	0.05	0.227	ns	0.482	4.52
n_s-sn	20	-2.90	2.10	-0.22	0.487	ns	1.045	4.60
n_s-prn	20	-2.80	1.70	-0.31	0.484	ns	1.046	4.67
Int to n-ss	20	-0.80	0.60	-0.06	0.153	ns	0.327	4.57

TABLE 14 (cont)

DISTRIBUTION OF THE DIFFERENCES BETWEEN THE DUPLICATE MEASUREMENTS

CL Sample

Variable	N	Min.	Max.	Mean Diff.	Standard error of Mean Difference	P	S(i)	S(i)%
$s\text{-}n_s\text{-}unt$	20	-2.80	3.30	-0.08	0.693	ns	1.475	4.53
sto to NL	20	-0.80	1.30	0.05	0.213	ns	0.452	4.52
$s\text{-}n_s\text{-}ss_s$	20	-2.10	1.60	0.03	0.332	ns	0.705	4.49
sn to $Int\text{-}l_s$	20	-1.10	0.90	-0.19	0.199	ns	0.360	3.26
ls to NCL	20	-0.30	1.20	0.32	0.173	ns	0.434	6.19
sto to ML	20	-2.40	1.10	-0.24	0.296	ns	0.650	4.82
$s\text{-}n_s\text{-}sm_s$	20	-1.10	1.30	0.03	0.255	ns	0.542	4.51
sm_s to $li\text{-}pg_s$	20	-0.80	0.70	-0.01	0.145	ns	0.330	5.19
li to NCL	20	-2.00	0.90	-0.20	0.259	ns	0.342	4.18
$ss_s\text{-}n_s\text{-}sm_s$	20	-0.80	1.20	-0.07	0.207	ns	0.442	4.55
sto to OL_s	20	-1.50	1.30	-0.01	0.280	ns	0.374	7.98
$S\text{-}n_s\text{-}pg_s$	20	-1.00	2.00	0.15	0.301	ns	0.647	4.63
NFL/NCL	20	-0.70	1.00	0.10	0.194	ns	0.418	4.62

RESULTS

5.1 DIFFERENCES BETWEEN THE CONTROL SAMPLE AND THE ANOMALY SAMPLE BEFORE TREATMENT

A) Nasal Airway Resistance

Nasal airway resistance was recorded bilateral for the total nasopharyngeal airway in all subjects, as well as unilaterally for each nasal half. This enabled a general comparison of total upper airway resistance to be made, and also provided a breakdown of the resistance of each nasal component.

Comparisons of the mean rhinomanometric variables between males and females in the control groups revealed only 3 statistically significant differences ($p<0.05$) out of a total of 18 separate comparisons (see Tables 15 and 16).

Similar comparisons between males and females in the anomaly sample before treatment revealed no statistically significant differences between the means (Tables 17 and 18).

It was concluded that for the purposes of comparing the rhinomanometric variables between the control sample and the anomaly sample before treatment, it would be reasonable to combine the data for the sexes.

Total upper airway resistance

An overview of all the rhinomanometric values of the control sample and anomaly sample before treatment including the laminar and turbulent components is shown in Table 21. There were no significant differences for nasal airway resistance. If one however turns to the laminar and turbulent components of the comparison of total airway resistance expressed in pascals/cc/second x 10^3 (Table 22), there is a statistically significant difference between the mean laminar flow on inspiration (150.27 for the control sample against 196.84 for the anomaly sample before treatment), for the laminar

component of expiration (146.45 for the control against 186.53 for the anomaly sample before treatment), as well as in the turbulent component (353.47 for the control sample compared with 714.85 for the anomaly sample before treatment on inspiration) and for the turbulent component of expiration (352.76 for the control sample compared with 710.56 for the anomaly sample before treatment).

Unilateral nasal respiratory resistance

The unilateral analysis of nasal resistance in the control group measured against the anomaly sample before treatment showed statistically significant differences at the $p<0.001$ level, for both inspiration and expiration, measured on both right and left sides. The values for the anomaly sample before treatment were considerably higher than for the control sample (see Table 21). The mean values in pascals/cc/second x 10^3 for the control sample ranged from ANT L EXP of 603.52 to ANT R EXP of 632.87. The mean values in the anomaly sample before treatment ranged from 819.48 for ANT R EXP to 827.98 for ANT R INSP.

For laminar and turbulent flow statistically significant differences were found between controls and anomaly samples (Table 22). The mean laminar flow values for the control sample ranged from 190.04 for the laminar L EXP to 203.86 for the laminar R EXP whereas those for the anomaly sample before treatment ranged from 239.43 for the laminar L EXP to 267.27 for the laminar R INSP, ($p<0.001$).

The range of the turbulent flow was from 845.83 for the L EXP value to 916.64 for the R INSP value in the controls, as compared with a range of 1233.87 for R EXP to 1328.92 for L INSP in the anomaly sample before treatment.

TABLE 15

NASAL AIRWAY RESISTANCE - CONTROL SAMPLE
N A R (pascals/cc/sec x 10^3) at 150 pascals

Variable	male Number*	Min	Max	Mean	S.D.	female Number*	Min	Max	Mean	S.D.	Diff.	t	p
ANT L													
INSP	9	265	721	524.22	143.59	16	333	1070	670.87	194.79	+146.65	-1.97	0.061
EXP	9	247	744	504.66	144.67	16	303	1084	659.13	203.32	+154.47	-2.00	0.057
ANT R													
INSP	9	452	868	606.78	132.04	14	366	1169	648.21	219.71	+41.43	-0.51	0.617
EXP	9	452	882	596.33	145.71	14	348	1196	656.38	230.79	+60.05	-0.69	0.496
POST													
INSP	11	274	702	437	129.94	22	250	683	429.14	101.95	- 7.86	0.19	0.852
EXP	11	264	628	410	118.95	22	242	699	415.29	111.67	+ 5.29	-0.12	0.902

* The number varies because certain subjects were unable to complete all tests

TABLE 16

NASAL AIRWAY RESISTANCE - CONTROL SAMPLE

Laminar and Turbulent flow coefficients K1/K2 (pascals/cc/sec x 10^3) at 150 pascals

Variable	male Number*	Min	Max	Mean	S.D.	female Number*	Min	Max	Mean	S.D.	Diff.	t	p
K_1 L INS	9	100	280	186.00	54.87	16	110	412	198.13	75.39	+ 12.13	-0.40	0.641
K_1 L EXP	9	113	279	184.88	49.53	16	115	317	192.80	62.87	+ 7.92	-0.31	0.702
K_1 R INSP	9	109	270	177.78	45.61	14	124	334	208.92	50.00	+ 31.14	-1.47	0.104
K_1 R EXP	9	107	265	178.44	44.17	14	126	366	222.92	65.59	+ 44.48	-1.75	0.042
K_1 P INS	11	117	204	158.44	28.58	22	92	294	146.76	45.28	- 11.68	0.71	0.414
K_1 P EXP	11	100	192	149.89	30.77	22	91	314	145.05	46.24	- 4.84	0.29	0.742
K_2 L INS	9	792	1227	1061.25	167.23	16	312	1204	762.75	321.72	-298.50	2.45	0.038
K_2 L EXP	9	789	1212	1036.38	171.05	16	260	1151	744.20	323.67	-292.18	2.37	0.034
K_2 R INS	9	660	1306	1029.78	240.07	14	336	1219	838.31	325.06	-191.47	1.50	0.142
K_2 R EXP	9	656	1302	1001.33	226.20	14	363	1191	831.77	322.94	-169.56	1.36	0.131
K_2 P INS	11	225	656	366.36	117.19	22	115	710	348.71	133.52	- 17.65	0.41	0.641
K_2 P EXP	11	188	658	354.00	125.42	22	124	653	352.14	125.66	- 1.86	0.04	0.943

TABLE 17

NASAL AIRWAY RESISTANCE - ANOMALY SAMPLE BEFORE TREATMENT
N A R (pascals/cc/sec x 10^3) at 150 pascals

Variable	male Number*	Min	Max	Mean	S.D.	female Number*	Min	Max	Mean	S.D.	Diff.	t	p
ANT L													
INSP	27	473	1602	828.44	246.12	32	460	1746	827.44	220.76	-1.00	0.02	0.987
EXP	27	475	1590	828.36	255.80	32	425	1668	823.22	207.00	-5.14	0.08	0.933
ANT R													
INSP	25	477	1219	797.12	216.00	30	494	1565	853.70	237.67	+56.58	-0.92	0.364
EXP	25	438	1312	808.33	230.75	30	461	1514	828.40	231.29	+20.07	-0.32	0.752
POST													
INSP	27	302	971	493.03	172.42	31	324	880	481.29	124.01	-11.74	0.30	0.765
EXP	27	293	900	467.33	166.22	31	306	806	453.55	115.58	-13.78	0.37	0.712

* The number varies because certain subjects were unable to complete all tests

TABLE 18

NASAL AIRWAY RESISTANCE - ANOMALY SAMPLE BEFORE TREATMENT

Laminar and Turbulent flow coefficients K1/K2 (pascal/cc/sec x 10^3) at 150 pascals

Variable	male Number*	Min	Max	Mean	S.D.	female Number*	Min	Max	Mean	S.D.	Diff.	t	p
K_1 L INS	27	120	412	238.60	84.32	32	161	593	274.00	89.49	+ 35.40	-1.48	0.146
K_1 L EXP	27	110	400	226.17	81.99	32	153	410	251.22	66.52	+ 25.05	-1.20	0.234
K_1 R INSP	25	110	448	243.57	87.21	30	171	876	292.05	147.31	+ 48.48	-1.35	0.184
K_1 R EXP	25	108	423	235.44	82.46	30	148	848	279.14	143.47	+ 43.70	-1.26	0.215
K_1 P INS	27	120	484	196.00	92.13	31	102	375	197.48	75.51	+ 1.48	-0.06	0.950
K_1 P EXP	27	97	478	187.55	98.67	31	100	367	185.76	70.12	- 1.79	0.08	0.940
K_2 L INS	27	563	1818	1331.33	329.92	32	452	1933	1327.04	308.52	- 4.29	0.05	0.963
K_2 L EXP	27	547	1934	1318.82	337.99	32	447	1800	1239.44	296.06	- 79.38	0.86	0.395
K_2 R INS	25	374	1822	1220.95	413.59	30	844	1907	1382.78	292.07	+161.83	-1.38	0.177
K_2 EXP	25	397	1770	1164.16	395.57	30	804	1887	1307.44	314.79	+143.28	-1.21	0.233
K_2 P INS	27	336	1571	732.46	303.15	31	177	1524	701.93	333.01	- 30.53	0.34	0.736
K_2 P EXP	27	322	1512	741.65	342.94	31	176	1354	688.38	306.14	- 53.27	0.57	0.574

* The numbers vary because certain subjects were unable to complete all tests

TABLE 19

NASAL AIRWAY RESISTANCE - ANOMALY SAMPLE AFTER TREATMENT
N A R (pascals/cc/sec x 10^3) at 150 pascals

Variable	male Number*	Min	Max	Mean	S.D.	female Number*	Min	Max	Mean	S.D.	Diff.	t	p
ANT L													
INSP	27	411	996	646.70	153.98	32	449	966	665.39	129.95	-18.69	-0.50	0.618
EXP	27	410	957	633.52	148.95	32	428	949	640.00	133.00	- 6.48	-0.17	0.864
ANT R													
INSP	25	441	827	610.39	102.28	30	356	1037	675.24	171.71	-64.85	-1.57	0.123
EXP	25	412	776	593.61	95.26	30	335	1069	665.56	187.18	-71.95	-1.66	0.105
POST													
INSP	27	289	590	365.93	57.56	31	249	883	421.89	133.32	-55.96	-2.01	0.049
EXP	27	279	511	344.78	51.04	31	222	851	402.10	131.53	-57.32	-2.12	0.039

* The number varies because certain subjects were unable to complete all tests

TABLE 20

NASAL AIRWAY RESISTANCE - ANOMALY SAMPLE AFTER TREATMENT
Laminar and Turbulent flow coefficients K1/K2 (pascal/cc/sec x 10^3) at 150 pascals

Variable	male Number*	Min	Max	Mean	S.D.	female Number*	Min	Max	Mean	S.D.	Diff.	t	p
K_1 L INS	27	100	295	161.04	49.39	32	126	268	192.04	36.68	-31.00	-2.57	0.013
K_1 L EXP	27	93	244	149.18	43.35	32	125	246	181.63	35.36	-32.45	-2.89	0.006
K_1 R INS	25	113	372	176.09	67.91	30	112	267	198.35	43.17	-22.26	-1.25	0.221
K_1 R EXP	25	105	368	167.16	61.19	30	121	305	190.75	46.91	-23.59	-1.36	0.183
K_1 P INS	27	62	178	116.75	30.47	31	70	259	144.22	50.79	-27.47	-2.15	0.037
K_1 P EXP	27	56	180	113.65	32.71	31	56	220	133.78	44.89	-20.13	-1.70	0.097
K_2 L INS	27	471	1841	998.00	307.64	32	297	1636	1000.04	328.21	- 2.04	-0.02	0.982
K_2 L EXP	27	512	1773	975.81	293.37	32	287	1660	957.04	328.24	18.77	0.20	0.839
K_2 R INS	25	276	1208	903.94	289.22	30	374	1854	991.89	401.57	-87.95	-0.76	0.452
K_2 R EXP	25	273	1268	845.35	301.95	30	343	1752	947.74	370.07	102.39	-0.90	0.373
K_2 P INS	27	132	900	437.95	165.54	31	137	1060	512.85	207.66	- 74.90	-1.35	0.183
K_2 P EXP	27	116	846	451.35	177.41	31	130	1040	501.19	205.08	- 49.84	-0.87	0.391

*The numbers vary because certain subjects were unable to complete all tests

TABLE 21

NASAL AIRWAY RESISTANCE: COMPARISON OF CONTROL AND ANOMALY SAMPLES BEFORE TREATMENT
N A R (pascals/cc/sec x 10^3) at 150 pascals

Variable	Control Sample Number*	Min	Max	Mean	S.D.	Anomaly Before Treatment Sample Number*	Min	Max	Mean	S.D.	Diff.	t	p
ANT L													
INSP	25	265	1070	618.08	189.08	57	460	1746	827.89	230.66	209.81	4.01	0.001
EXP	25	247	1084	603.52	196.31	57	425	1668	825.47	227.54	221.91	4.23	0.001
ANT R													
INSP	23	366	1169	632.00	187.86	55	477	1565	827.98	227.77	195.98	3.64	0.001
EXP	23	348	1196	632.87	200.24	55	438	1514	819.48	229.08	186.61	3.39	0.001
POST													
INSP	33	250	702	431.84	110.30	58	302	971	486.76	147.27	54.92	1.84	0.069
EXP	33	242	699	413.47	112.32	58	293	900	459.08	140.29	46.50	1.61	0.111

* The numbers vary because certain subjects were unable to complete all tests

TABLE 22

NASAL AIRWAY RESISTANCE: COMPARISON OF CONTROL AND ANOMALY SAMPLES BEFORE TREATMENT
Laminar and Turbulent flow coefficients K1/K2 (pascal/cc/sec x 10^3) at 150 pascals

Variable	Control Sample Number*	Min	Max	Mean	S.D.	Anomaly Before Treatment Sample Number*	Min	Max	Mean	S.D.	Diff.	t	p
ANT L													
INSP K_1	25	100	412	194.08	68.25	59	120	593	257.30	88.08	63.22	-3.11	0.003
EXP K_1	25	113	317	190.04	57.54	59	110	410	239.43	74.52	49.39	-2.82	0.006
ANT R													
INSP K_1	23	109	334	195.57	49.56	55	110	876	267.27	121.49	68.70	-2.60	0.012
EXP K_1	23	107	366	203.86	60.46	55	108	848	256.80	117.09	52.94	-1.95	0.056
POST													
INSP K_1	33	92	294	150.27	40.85	58	102	484	196.84	82.21	46.57	-2.89	0.005
EXP K_1	33	91	314	146.45	41.88	58	97	478	186.53	82.73	40.08	-2.51	0.014
ANT L													
INSP K_2	25	312	1227	862.25	310.93	59	452	1933	1328.92	314.61	466.67	-5.96	0.001
EXP K_2	25	260	1212	845.83	310.19	59	447	1934	1276.59	315.42	430.76	-5.40	0.001
ANT R													
INSP K_2	23	336	1306	916.64	302.68	55	374	1907	1297.61	365.70	380.97	-4.13	0.001
EXP K_2	23	363	1302	901.14	293.89	55	397	1887	1233.87	360.98	332.73	-3.66	0.001
POST													
INSP K_2	33	115	710	353.47	126.58	58	177	1571	714.85	318.01	361.38	-6.13	0.001
EXP K_2	33	124	658	352.76	123.61	58	176	1512	710.56	319.51	357.80	-6.12	0.001

*The numbers vary because certain subjects were unable to complete all tests

B) Transverse Craniofacial Dimensions

The measurements of the transverse dimensions on the postero-anterior cephalometric radiographs were compared between the sexes in the control sample, and the anomaly sample before treatment (Tables 23,24,25).

In the control sample there was a statistically significant difference ($p=0.035$) only between EMR-EML, the width of the maxillary base.

In the anomaly sample before treatment there were statistically significant differences in nasal width (L), CNM-CNL ($p=0.010$), maxillary base width EMR-EML ($p=0.004$) and lower molar width LMR-LML ($p=0.033$).

In practical terms it appeared reasonable to combine the male and female values in the control sample and the anomaly sample before treatment because the differences between the mean values were so small.

In the anomaly sample after treatment, more variables showed statistically significant differences between the mean values for males and females: EMR-EML ($p=0.007$) and UMR-UML ($p=0.035$), LMR-LML ($p=0.032$), MIR-MIL ($p=0.047$) and MIR-C_2 ($p=0.030$), the male mean value being consistently larger than the female in all cases.

Separate consideration will therefore be given to each sex in a subsequent analysis. Consideration will also be given to the variable EMR-EML, which was found to be statistically significantly greater in males in all three samples.

The mean transverse dimensions are shown in Table 26. Comparison between the control sample and the anomaly sample before treatment showed a number of statistically significant differences at the $p<0.001$ and $p<0.05$ levels, particularly in respect to the horizontal values, all of which were smaller in the treatment (see Figure 35).

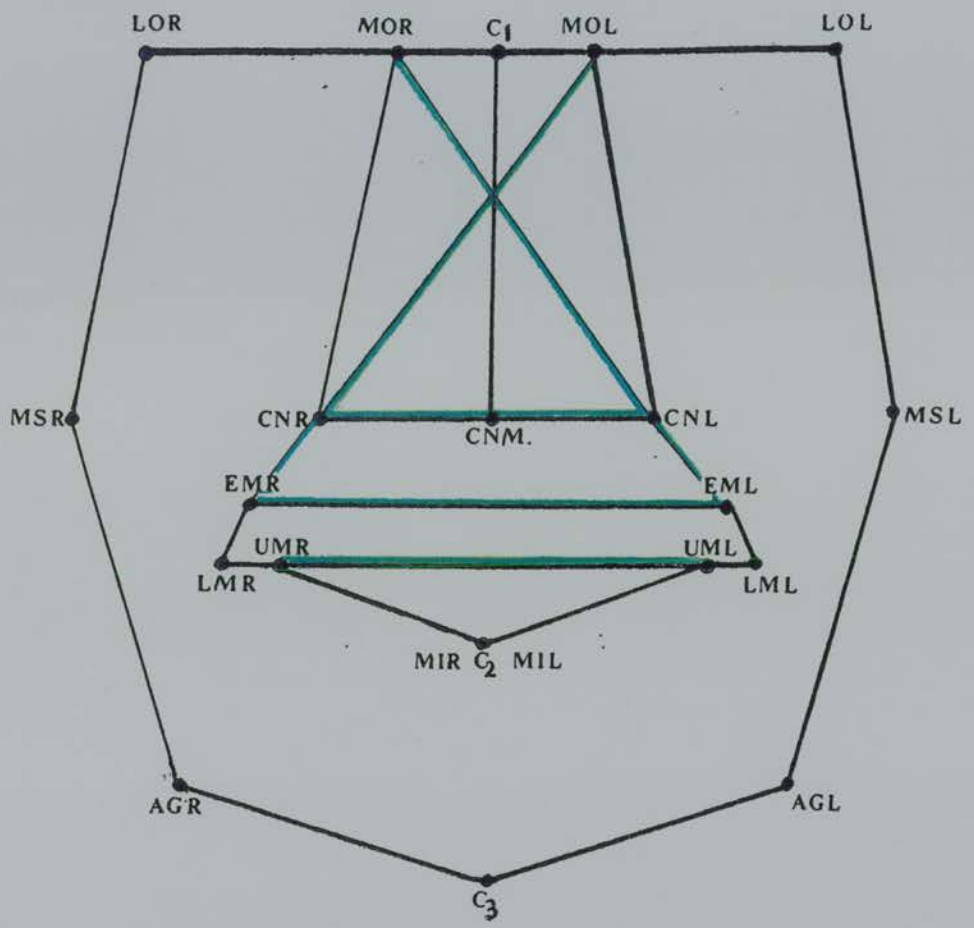
The measurement CNR-CNL showed a mean value of 29.64mm in the control sample and 28.00mm in the anomaly sample before treatment ($p < 0.005$), showing that the width of the anterior nasal floor was significantly smaller in the anomaly sample before treatment than in the control group by some 6%.

The measurement EMR-EML in the control sample had a mean value of 63.87mm, compared with 60.99mm in the anomaly sample before treatment - the difference was statistically significant at the $p < 0.001$ level. The measurement UMR-UML had a mean value of 61.21mm in the control sample and 53.86mm in the anomaly sample before treatment ($p < 0.001$). Hence the maxillary base width and the width between the lateral points on the maxillary molars were significantly narrower in the anomaly sample before treatment than in the control sample.

The variable NAS DIM, which comprises a line from MOR to CNL and a line from MOL to CNR, showed significant differences between the two samples at the $p < 0.001$ level, as did the variable MAX DIM which comprises a line from MOR to EML and a line from MOL to EMR, all measured in mm.

The mean values for NAS DIM were 70.79 for the control sample against 66.99 for the anomaly before sample. The values for MAX DIM were 82.31 for the control and 78.31 for the anomaly before sample.

POSTERO ANTERIOR CEPHALOMETRIC RESULTS



SIGNIFICANT DIFFERENCES

CONTROL SAMPLE/ANOMALY SAMPLE BEFORE TREATMENT

Fig. 35

TABLE 23

TRANSVERSE CEPHALOMETRIC DIMENSIONS IN MM - CONTROL SAMPLE

Variable	male Number	Min	Max	Mean	S.D.	female Number	Min	Max	Mean	S.D.	Diff.	t	p
CNR-CNM	12	13.9	20.6	16.45	1.95	24	14.3	19.5	16.66	1.53	+0.21	-0.35	0.732
CNM-CNL	12	14.2	19.3	16.22	1.71	24	14.0	18.9	16.39	1.57	+0.17	-0.31	0.760
CNR-CNL	12	26.3	34.9	29.63	3.05	24	25.80	34.60	29.65	2.33	+0.02	-0.01	0.993
EMR-EML	12	57.9	69.5	65.63	2.98	24	54.70	69.80	62.99	3.57	-2.64	2.20	0.041
UMR-UML	12	54.4	64.7	62.03	2.94	24	53.80	67.00	60.80	3.35	-1.23	1.08	0.294
LMR-LML	12	49.0	65.4	58.78	4.30	24	50.80	63.60	56.47	3.39	-2.31	1.77	0.091
MIR-MIL	12	00.0	2.60	0.43	0.89	24	0.00	4.10	0.46	1.09	+0.03	-0.10	0.922
MIR-C2	12	00.0	1.30	0.23	0.44	24	0.00	2.60	0.27	0.63	+0.04	-0.20	0.840
C2-MIL	12	00.0	1.30	0.22	0.44	24	0.00	1.50	0.21	0.47	-0.01	0.05	0.962
NAS-DIM	12	65.5	86.00	72.00	5.75	24	62.00	84.00	70.18	5.65	-0.82	-0.91	0.371
MAX-DIM	12	67.2	95.10	83.43	5.69	24	75.10	91.10	81.75	4.82	-1.68	-0.93	0.363

TABLE 24

TRANSVERSE CEPHALOMETRIC DIMENSIONS IN MM - ANOMALY SAMPLE BEFORE TREATMENT

	male					female							
Variable	Number	Min	Max	Mean	S.D.	Number	Min	Max	Mean	S.D.	Diff.	t	p
CNR-CNM	31	12.8	19.5	16.23	1.76	41	12.9	19.9	15.48	1.65	-0.75	1.87	0.070
CNM-CNL	31	11.9	20.0	15.97	1.88	41	12.5	18.1	14.94	1.46	-1.03	2.64	0.010
CNR-CNL	31	23.1	35.0	28.75	2.98	41	20.2	33.0	27.44	2.83	-1.31	1.90	0.062
EMR-EML	31	53.6	68.8	62.65	4.19	41	51.5	67.8	59.74	3.93	-0.91	3.02	0.004
UMR-UML	31	44.2	66.2	54.93	4.99	41	44.2	60.2	53.05	4.12	-1.88	1.75	0.090
LMR-LML	31	48.9	70.7	59.70	4.30	41	44.4	67.24	57.51	4.17	-2.19	2.18	0.033
MIR-MIL	31	0.0	5.3	0.58	1.38	41	0.00	2.3	0.22	0.51	-0.36	1.55	0.127
MIR-C2	31	0.0	2.4	0.27	0.58	41	0.00	1.2	0.13	0.23	-0.14	1.40	0.170
C2-MIL	31	0.0	3.4	0.34	0.81	41	0.00	1.4	0.12	0.29	-0.22	1.63	0.120
NAS-DIM	31	58.3	79.0	67.67	4.59	41	55.5	79.5	66.48	5.71	-1.19	-0.95	0.348
MAX-DIM	31	68.4	86.8	78.13	4.67	41	69.1	89.5	78.45	5.90	+0.32	0.25	0.803

TABLE 25

TRANSVERSE CEPHALOMETRIC DIMENSIONS IN MM - ANOMALY SAMPLE AFTER TREATMENT

Variable	male Number	Min	Max	Mean	S.D.	female Number	Min	Max	Mean	S.D.	Diff.	t	p
CNR-CNM	31	14.7	21.5	17.41	1.58	41	14.6	20.2	16.75	1.41	-0.66	1.87	0.065
CNM-CNL	31	14.4	20.8	17.22	1.48	41	11.6	20.2	16.45	1.82	-0.77	1.92	0.058
CNR-CNL	31	24.5	37.3	31.51	2.72	41	25.0	37.5	30.55	2.91	-0.96	1.42	0.159
EMR-EML	31	56.9	76.6	64.60	4.51	41	54.4	71.0	62.03	3.29	-2.57	2.80	0.007
UMR-UML	31	51.7	72.5	62.93	5.44	41	50.2	66.0	60.64	3.57	-2.29	2.15	0.035
LMR-LML	31	49.9	70.8	60.05	4.29	41	44.5	68.1	57.86	4.11	-2.19	2.19	0.032
MIR-MIL	31	2.7	7.7	5.54	1.49	41	2.3	8.2	4.82	1.51	-0.72	2.03	0.047
MIR-C2	31	1.1	3.9	2.69	0.76	41	1.1	3.9	2.29	0.78	-0.40	2.21	0.030
C2-MIL	31	1.5	4.2	2.85	0.77	41	1.1	4.3	2.54	0.78	-0.31	1.69	0.096
NAS-DIM	31	58.3	82.5	70.18	5.11	41	56.0	82.0	68.97	6.18	-1.21	0.89	0.380
MAX-DIM	31	68.0	90.3	78.28	5.06	41	69.0	90.0	78.87	5.42	+0.59	0.47	0.640

TABLE 26

COMPARISON OF TRANSVERSE CEPHALOMETRIC DIMENSIONS IN MM BETWEEN CONTROL AND ANOMALY SAMPLES

Variable	Control Sample					Anomaly Before Sample							
	Number	Min	Max	Mean	S.D.	Number	Min	Max	Mean	S.D.	Diff.	t	p
CNR-CNM	36	13.90	20.60	16.55	1.74	72	12.80	19.90	15.85	1.70	-0.70	2.27	0.025
CNM-CNL	36	14.00	19.30	16.31	1.77	72	11.90	20.00	15.46	1.670	-0.85	2.78	0006
CNR-CNL	36	25.80	34.90	29.64	2.275	72	20.20	35.00	28.00	2.948	-1.64	2.85	0.005
EMR-EML	36	54.70	69.80	63.87	3.570	72	51.50	68.80	60.99	4.271	-2.88	3.47	0.001
UMR-UML	36	53.80	67.00	61.21	3.232	72	44.20	66.20	53.86	4.579	-7.35	8.60	0.001
LMR-LML	36	49.00	65.40	57.24	3.822	72	44.40	70.70	58.45	4.340	1.21	-1.42	0.157
MIR-MIL	36	0.00	4.10	0.45	1.012	72	0.000	5.30	0.38	0.991	-0.07	0.37	0.713
MIR-C2	36	0.00	2.60	0.25	0.570	72	0.00	2.40	0.19	0.418	-0.06	0.66	0.510
C2-MIL	36	0.00	1.50	0.21	0.452	72	0.00	3.40	0.21	0.577	0.00	-0.01	0.990
NAS-DIM	36	62.00	86.00	70.79	5.668	72	55.50	79.50	66.99	5.258	-3.80	-3.45	0.001
MAX-DIM	36	67.20	95.10	82.31	5.108	72	68.40	89.50	78.31	5.373	4.00	-3.71	0.001

C) Head Posture

The mean head posture measurements of the control sample in males and females (Table 27, 28,29) showed no statistically significant differences. In the anomaly sample before treatment, statistically significant differences between the sexes were found for NL/VER and CVT/HOR ($p<0.05$) and in the same sample after treatment the mean values of NSL/CVT and CVT/HOR showed statistically significant differences between males and females ($p<0.05$). In all the instances the mean values for males exceeded those for females.

It was concluded however that, for the purposes of this investigation, it would be reasonable to combine the data for the sexes in each of the three groups.

The comparison of head posture variables in the control sample with those in the anomaly sample before treatment (see Table 30) showed no statistically significant differences.

However, the variables associated with a backwards inclination of the head showed a definite trend, with the larger values in the anomaly sample before treatment. Hence NSL/VER showed a mean value of 95.33° in the control group compared with a mean value of 96.69° in the anomaly group before treatment. The mean values of NSL/OPT were 98.85° in the control group and 101.41° in the anomaly group before treatment. The corresponding values of NSL/CVT were 103.85° and 105.47° respectively.

The values NSL/CVT and NSL/OPT have particular relevance as these were the values used in previous studies (Siersbaek-Nielsen and Solow 1982: Solow et al 1984: Sandham 1987) to determine craniocervical angulation, as they lie remote from the areas directly affected by the mechanical aspects of RME.

TABLE 27

HEAD POSTURE IN DEGREES - CONTROL SAMPLE

Value	male n = 12 Number	Min	Max	Mean	S.D.	female n = 24 Number	Min	Max	Mean	S.D.	Diff.	t	p
NSL/VER	12	82.6	110.0	94.68	8.24	24	85.8	107.3	95.67	6.29	0.99	-0.40	0.690
NL/VER	12	80.5	104.0	88.17	7.31	24	72.0	102.5	87.44	7.43	0.73	0.28	0.780
NSL/OPT	12	80.8	108.2	97.45	7.70	24	81.4	115.9	99.55	9.53	2.10	-0.66	0.513
NSL/CVT	12	86.3	115.3	100.47	7.34	24	89.3	123.5	105.55	9.16	5.08	-1.67	0.100
NL/OPT	12	70.0	100.5	91.28	9.00	24	73.8	111.1	91.62	9.49	0.34	-0.10	0.920
NL/CVT	12	75.4	104.6	94.28	7.78	24	81.7	118.6	97.62	9.24	3.34	-1.07	0.290
OPT/HOR	12	74.7	100.9	87.23	7.44	24	68.5	102.9	86.11	8.64	-1.12	0.38	0.700
CVT/HOR	12	75.4	95.4	84.18	6.28	24	64.7	94.0	80.11	7.98	-4.07	1.54	0.130
FH/VER	12	76.5	102.4	86.38	9.08	24	72.2	101.2	84.34	5.96	-2.04	0.81	0.420
FH/OPT	12	72.3	103.4	89.14	8.55	24	74.4	107.1	88.22	9.08	-0.92	0.29	0.770
FH/CVT	12	77.8	106.6	92.17	7.98	24	81.7	111.0	94.24	8.76	2.07	-0.69	0.490

TABLE 28

HEAD POSTURE IN DEGREES - ANOMALY SAMPLE BEFORE TREATMENT

	male n = 31					female n = 41							
Value	Number	Min	Max	Mean	S.D.	Number	Min	Max	Mean	S.D.	Diff.	t	p
NSL/VER	31	79.4	109.2	97.36	6.43	41	79.8	106.6	96.18	6.09	-1.18	0.80	0.433
NL/VER	31	78.0	100.5	89.63	6.11	41	64.0	97.0	86.44	6.74	-3.19	2.07	0.044
NSL/OPT	31	80.6	114.3	101.72	8.45	41	83.2	119.0	101.18	9.30	-0.54	0.25	0.804
NSL/CVT	31	83.1	118.8	104.22	7.61	41	87.3	123.6	106.42	8.98	2.20	-1.10	0.280
NL/OPT	31	80.3	108.7	94.26	7.49	41	72.8	104.9	91.69	8.81	-2.57	1.30	0.194
NL/CVT	31	85.3	113.2	96.77	6.84	41	77.8	109.5	96.92	8.65	0.15	-0.08	0.941
OPT/HOR	31	72.2	102.8	85.65	7.74	41	71.8	98.6	84.99	6.60	-0.66	0.38	0.703
CVT/HOR	31	72.2	99.0	83.15	6.80	41	65.9	91.7	79.77	6.19	-3.38	2.19	0.034
FH/VER	31	72.0	104.1	87.27	6.54	41	70.0	98.0	84.38	6.24	-2.89	1.19	0.064
FH/OPT	31	73.2	101.2	91.63	7.72	41	70.3	104.3	89.38	8.74	-2.25	1.13	0.263
FH/CVT	31	75.7	105.0	94.12	6.91	41	74.4	109.2	94.61	8.20	0.49	-0.27	0.792

TABLE 29

HEAD POSTURE IN DEGREES - ANOMALY SAMPLE AFTER TREATMENT

	male n =31					female n =41							
Value	Number	Min	Max	Mean	S.D.	Number	Min	Max	Mean	S.D.	Diff.	t	p
NSL/VER	31	83.2	104.5	95.45	5.81	41	85.6	109.2	96.81	5.70	1.36	-0.99	0.325
NL/VER	31	75.5	98.0	86.97	5.52	41	71.0	96.5	86.79	5.82	-0.18	0.13	0.898
NSL/OPT	31	80.6	115.6	101.24	8.86	41	88.5	124.4	102.91	8.70	1.67	-0.80	0.426
NSL/CVT	31	84.8	115.1	103.41	8.02	41	92.6	128.0	108.03	8.12	4.62	-2.40	0.019
NL/OPT	31	77.6	105.1	93.01	7.51	41	77.8	111.1	93.15	8.26	0.14	-0.07	0.941
NL/CVT	31	82.2	106.8	95.17	6.77	41	85.9	114.7	98.26	7.82	3.09	-1.76	0.083
OPT/HOR	31	69.5	106.0	84.21	7.71	41	68.8	98.1	83.90	7.62	-0.31	0.17	0.864
CVT/HOR	31	69.0	100.3	82.04	6.65	41	65.1	89.9	78.78	6.37	-3.26	2.11	0.038
FH/VER	31	72.8	96.4	85.59	5.88	41	73.0	94.7	85.01	5.43	-0.58	0.43	0.669
FH/OPT	31	72.3	104.0	91.39	8.13	41	74.2	107.1	91.11	7.96	-0.28	0.15	0.882
FH/CVT	31	76.5	103.5	93.55	7.37	41	79.8	110.5	96.25	7.29	2.70	-1.55	0.126

TABLE 30

COMPARISON OF HEAD POSTURE IN DEGREES BETWEEN CONTROL AND ANOMALY SAMPLES

Variable	Control Sample					Anomaly Before Treatment Sample							
	Number	Min	Max	Mean	S.D.	Number	Min	Max	Mean	S.D.	Diff.	t	p
NSL/VER	36	82.6	110.0	95.34	6.89	72	79.4	109.2	96.69	6.22	1.35	-1.02	0.308
NL/VER	36	72.0	104.0	87.68	7.29	72	64.0	100.5	87.81	6.63	0.13	-0.09	0.925
NSL/OPT	36	80.8	115.9	98.85	8.91	72	80.6	119.0	101.41	8.89	2.56	-1.41	0.161
NSL/CVT	36	86.3	123.5	103.86	8.83	72	83.1	123.6	105.47	8.43	1.61	-0.92	0.358
NL/OPT	36	70.0	111.1	91.50	9.20	72	72.8	108.7	92.80	8.32	1.30	-0.74	0.462
NL/CVT	36	75.4	118.6	96.50	8.82	72	77.8	113.2	96.85	7.87	0.35	-0.21	0.835
OPT/HOR	36	68.5	102.9	86.49	8.17	72	71.8	102.8	85.28	7.07	-1.21	0.80	0.428
CVT/HOR	36	64.7	95.4	81.47	7.62	72	65.9	99.0	81.23	6.63	-0.24	0.17	0.864
FH/VER	36	72.2	102.4	85.02	7.09	72	70.0	104.1	85.63	6.49	0.61	-0.45	0.657
FH/OPT	36	72.3	107.1	88.53	8.79	72	70.3	104.3	90.35	8.34	1.83	-1.05	0.295
FH/CVT	36	77.8	111.0	93.55	8.46	72	74.4	109.2	94.39	7.63	0.84	-0.53	0.599

D) Airway Dimensions

When the data on airway dimensions was examined to check on the acceptability of combining the mean values for males and females in the two groups of subjects (Tables 31,32,33) it was found that in the anomaly sample before and after treatment, the mean value for pm-ad_3 was significantly larger in males ($p<0.05$).

In the control group, the mean value of tu-ad_3 was significantly greater in females ($p=0.012$). Caution must therefore be exercised in pooling male and female values relating to the airway dimensions pm-ad_3 and tu-ad_3.

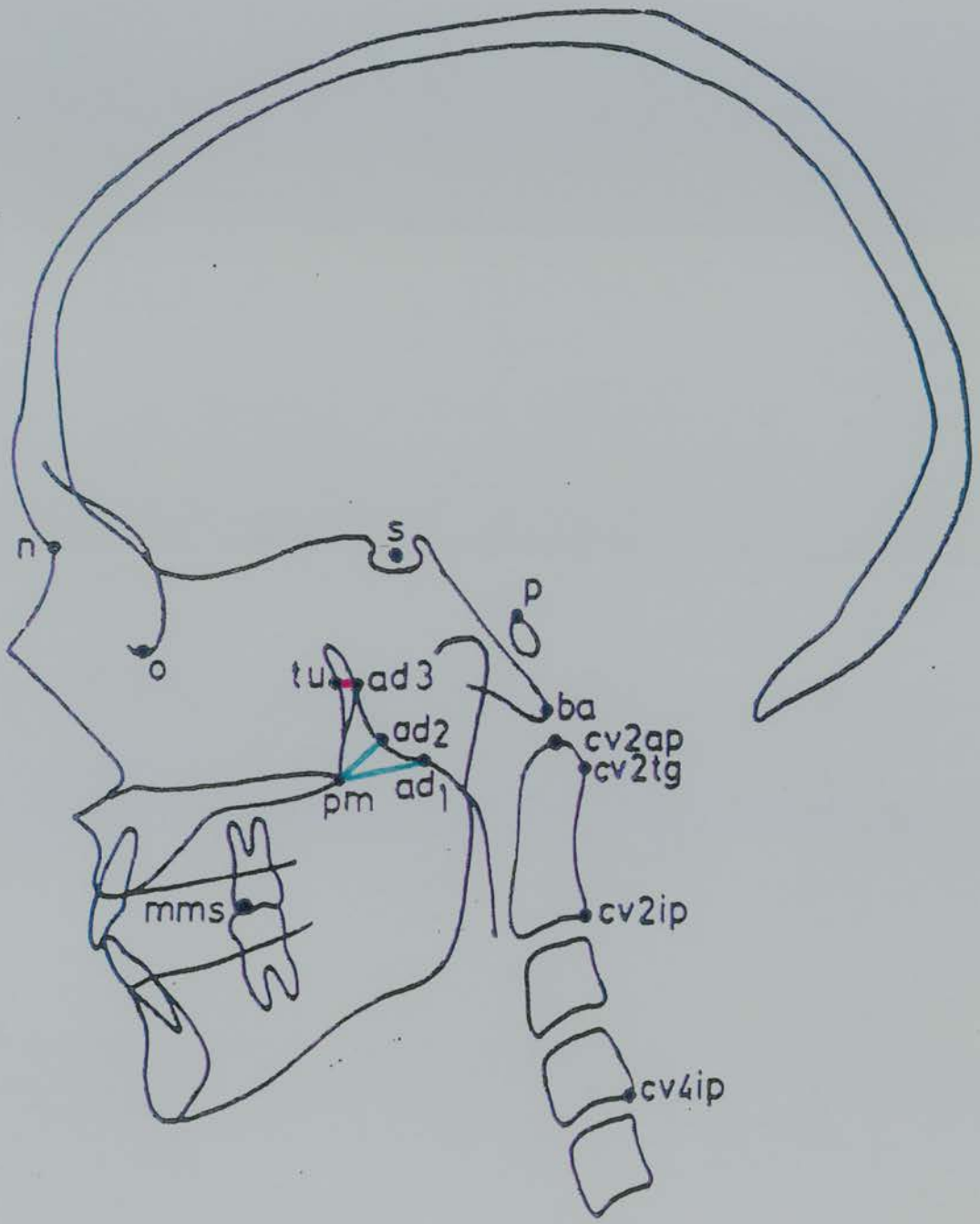
The comparison of the control and anomaly samples before treatment are shown in Table 34.

The mean variables pm-ad_1 and pm-ad_2 were larger in the control group, the differences being highly significant ($p<0.001$). The actual mean values of pm-ad_1 in the control and anomaly groups were 22.03mm and 18.12mm respectively. For pm-ad_2 the means were 17.29mm and 13.98mm respectively (see Figure 36).

Data for males and females were not combined when the variables pm-ad_3 and tu-ad_3 were considered. Comparison of the control group and the anomaly group for each sex (Tables 35 36) showed that pm-ad_3 was significantly smaller ($p<0.05$) in the male control sample. The tu-ad_3 differences were highly significant in both males and females ($p<0.001$), the male control sample mean being 4.03mm against the male anomaly sample before treatment mean value of 6.90mm, a difference of 2.87mm; the female control sample mean value was 4.99mm against the female anomaly before treatment mean value of 6.93mm, a difference of 1.94mm.

There exists a difference in form between the control and anomaly before treatment samples with regard to airway dimensions. The anomaly sample before treatment is narrower in the dimensions pm-ad_1 and pm-ad_2, but wider at the top of the airway chamber as measured by tu-ad_3.

AIRWAY DIMENSION RESULTS



SIGNIFICANT DIFFERENCES

CONTROL SAMPLE/ANOMALY SAMPLE BEFORE TREATMENT

Fig. 36

TABLE 31

AIRWAY DIMENSIONS IN MM - CONTROL SAMPLE

	male n = 12					female n = 24							
Value	Number	Min	Max	Mean	S.D.	Number	Min	Max	Mean	S.D.	Diff.	t	p
$pm\text{-}ad_1$	12	13.2	26.4	20.06	4.27	24	10.3	35.3	23.01	6.27	2.95	-1.47	0.154
$pm\text{-}ad_2$	12	7.6	21.9	16.23	4.66	24	10.1	29.1	17.82	4.92	1.59	-0.93	0.363
$pm\text{-}ad_3$	12	14.3	29.1	22.68	4.22	24	16.9	30.5	22.92	3.44	0.24	-0.18	0.861
$tu\text{-}ad_3$	12	2.9	5.0	4.03	0.66	24	2.5	7.9	4.99	1.16	0.96	-2.66	0.012

TABLE 32

AIRWAY DIMENSIONS IN MM - ANOMALY SAMPLE BEFORE TREATMENT

Value	male n = 31 Number	Min	Max	Mean	S.D.	female n = 41 Number	Min	Max	Mean	S.D.	Diff.	t	p
$pm\text{-}ad_1$	31	6.9	29.2	18.29	5.28	41	4.6	27.5	18.00	5.48	-0.29	0.22	0.822
$pm\text{-}ad_2$	31	7.3	20.6	14.47	3.57	41	4.6	22.0	13.60	4.43	-0.87	0.89	0.384
$pm\text{-}ad_3$	31	20.1	32.3	24.74	2.33	41	15.3	29.1	22.99	3.39	-1.75	2.46	0.0164
$tu\text{-}ad_3$	31	3.2	9.6	6.90	1.59	41	3.7	12.3	6.93	2.09	-0.03	-0.08	0.940

TABLE 33

AIRWAY DIMENSIONS IN MM - ANOMALY SAMPLE AFTER TREATMENT

	male n = 31					female n = 41							
Value	Number	Min	Max	Mean	S.D.	Number	Min	Max	Mean	S.D.	Diff.	t	p
$pm\text{-}ad_1$	31	8.0	28.3	19.91	5.39	41	7.5	28.9	19.42	5.58	-0.49	0.37	0.714
$pm\text{-}ad_2$	31	6.5	22.1	14.84	3.49	41	6.8	21.0	14.67	3.78	-0.17	0.19	0.846
$pm\text{-}ad_3$	31	21.1	31.0	24.96	2.46	41	12.9	29.1	23.16	3.37	-1.80	2.50	0.015
$tu\text{-}d_3$	31	5.0	13.0	7.24	1.69	41	3.6	12.9	7.03	1.74	-0.21	0.52	0.605

TABLE 34

COMPARISON OF AIRWAY DIMENSIONS IN MM BETWEEN CONTROL AND ANOMALY SUBJECTS BEFORE TREATMENT

Variable	Control Number	Min	Max	Mean	S.D.	Anomaly Before Treatment Number	Min	Max	Mean	S.D.	Diff.	t	p
$pm\text{-}ad_1$	36	10.30	35.30	22.03	5.794	72	4.6	29.2	18.12	5.359	-3.91	3.47	0.001
$pm\text{-}ad_2$	36	7.60	29.10	17.29	4.825	72	4.6	22.0	13.98	4.078	-3.31	3.74	0.001
$pm\text{-}ad_3$	36	14.30	30.50	22.84	3.657	72	15.3	32.3	23.75	3.083	0.91	-1.35	0.179
$tu\text{-}ad_3$	36	2.50	7.90	4.51	0.911	72	3.2	12.3	6.92	1.88	2.40	-6.60	0.001

TABLE 35

COMPARISON OF AIRWAY DIMENSIONS IN MM BETWEEN
MALE CONTROL SUBJECTS AND MALE ANOMALY SUBJECTS BEFORE TREATMENT

Variable	Control Sample					Anomaly Sample Before Treatment							
	Number	Min	Max	Mean	S.D.	Number	Min	Max	Mean	S.D.	Diff.	t	p
pm-ad$_3$	12	14.3	29.1	27.68	4.22	31	20.1	32.3	24.74	2.33	-2.06	-2.04	0.054
tu-ad$_3$	12	2.9	5.0	4.03	0.66	31	3.2	9.6	6.90	1.59	2.87	-6.00	0.001

TABLE 36

COMPARISON OF AIRWAY DIMENSIONS IN MM BETWEEN
FEMALE CONTROL SUBJECTS AND FEMALE ANOMALY SUBJECTS BEFORE TREATMENT

Variable	Control Sample					Anomaly Sample Before Treatment							
	Number	Min	Max	Mean	S.D.	Number	Min	Max	Mean	S.D.	Diff.	t	p
$pm\text{-}ad_3$	24	16.9	30.5	22.92	3.44	41	15.3	29.1	22.99	3.39	0.07	-0.09	0.929
$tu\text{-}ad_3$	24	2.5	7.9	4.99	1.16	41	3.7	12.3	6.93	2.09	1.94	-4.17	0.001

E) Craniofacial Morphology - Linear Dimensions

Comparisons between male and female mean values of linear hard tissue variables in samples (see Tables 37,38,39) show several significant differences. The variable sp-pm (maxillary length) was significantly larger in males than in females in both samples. The overbite in the control sample was significantly deeper in the male group than the female ($p=0.02$).

In all other linear hard tissue variables, with the exception of n-sp, oj and ob, statistically significant differences were found in the anomaly sample before and after treatment, the differences for n-s, n-gn, s-ba, s-pm, s-tgo, sp-gn being significant at the $p<0.001$ level. The male values were consistently larger, reflecting the general difference in size between males and females in the chosen age band of 10 to 15 years inclusive.

It was concluded that it would be preferable to consider the data for each sex separately.

The comparison of the linear craniofacial variables of the control and the anomaly sample before treatment with RME (Tables 40,41,42) showed a number of statistically significant differences (see Figure 37).

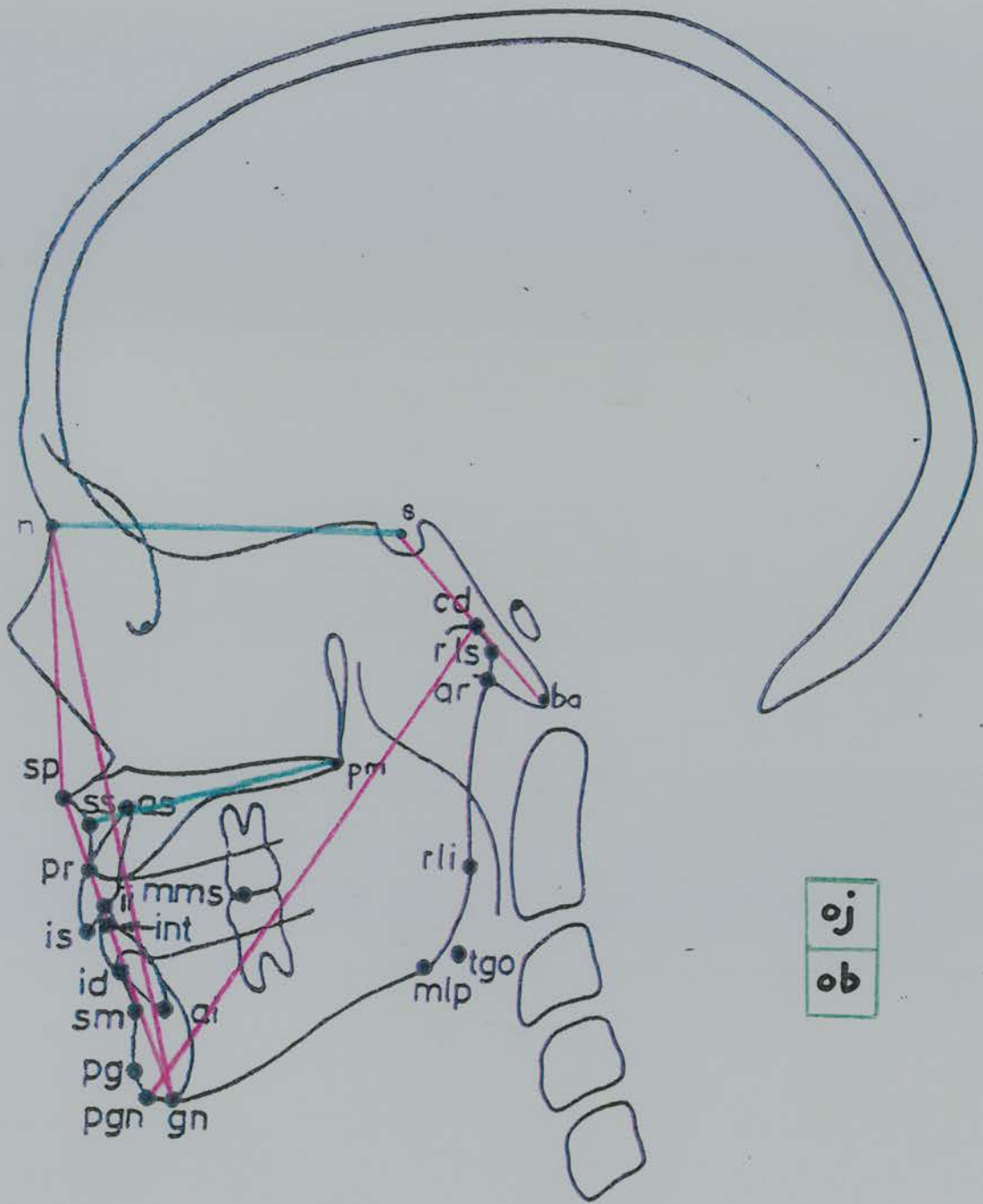
In those values which relate to the height of the anterior facial complex, the upper facial height n-sp, lower facial height sp-gn and total anterior facial height n-gn, all showed significantly different mean values in the male subjects only (see Table 41), being greater in the anomaly sample before treatment than in the control: n-sp had a mean difference of 2.88mm ($p=0.039$); sp-gn a mean difference of 5.97mm ($p<0.001$); and n-gn a mean difference of 9.68mm ($p<0.001$).

Also, only in the male subjects (see Table 41), the clivus length s-ba was significantly ($p=0.022$) larger in the anomaly sample before treatment by a mean difference of 2.93mm. For both males and females, the value of the variable

pgn-cd, a measurement of mandibular length, was also significantly greater ($p<0.001$) in the anomaly sample, there being an overall mean difference of 7.27m. However in two of the linear variables that measure facial depth, n-s and ss-pm, the values for the total anomaly sample were significantly less than those for the control sample, but when the sexes were considered separately the differences were statistically significant in the female subjects only (see Table 42). In females the variable n-s had a mean difference of 2.83mm ($p=0.003$) and ss-pm a mean difference of 2.09mm ($p=0.006$).

The overjet and overbite linear values were significantly different between the two samples in both males and females (see Tables 41,42). The overjet in the combined control sample was larger by a mean difference of 3.82mm ($p<0.001$) and the overbite deeper in the combined control sample by a mean difference of 2.50mm ($p<0.001$) (see Table 40).

CEPHALOMETRIC LINEAR RESULTS



SIGNIFICANT DIFFERENCES

CONTROL SAMPLE/ANOMALY SAMPLE BEFORE TREATMENT

Fig. 37

TABLE 37

CRANIOFACIAL MORPHOLOGY - LINEAR VALUES IN MM - CONTROL SAMPLE

	male n = 12					female n = 24							
Value	Number	Min	Max	Mean	S.D.	Number	Min	Max	Mean	S.D.	Diff.	t	p
n-s	12	69.9	81.3	73.95	3.21	24	65.8	81.9	73.97	3.82	0.02	-0.02	0.993
n-sp	12	47.1	56.2	52.66	3.13	24	44.3	59.5	53.30	3.54	0.64	-0.54	0.594
n-gn	12	110.8	127.7	118.56	5.18	24	107.1	133.1	119.10	7.29	0.54	-0.23	0.822
s-ba	12	38.3	50.3	45.93	3.22	24	33.8	50.4	45.13	4.15	-0.80	0.58	0.563
s-pm	12	43.3	57.1	49.34	3.87	24	38.7	54.0	48.20	3.87	-1.14	0.84	0.414
sp-gn	12	61.8	75.3	68.35	4.32	24	59.3	81.3	67.99	5.97	-0.36	0.19	0.854
sp-pm	12	50.9	61.9	56.56	3.54	24	46.9	61.5	53.94	3.25	-2.62	2.22	0.032
ss-pm	12	47.5	55.8	51.90	2.51	24	43.3	55.5	50.53	2.50	-1.37	1.55	0.131
pgn-cd	12	106.9	126.2	115.67	4.82	24	97.4	125.8	114.41	6.57	-1.26	0.59	0.564
oj	12	3.8	9.9	6.41	1.87	24	3.8	11.4	6.28	2.10	-0.13	0.17	0.863
ob	12	-7.3	-3.5	-4.83	0.94	24	-7.9	0.4	-3.52	1.72	-1.31	-2.46	0.024

.TABLE 38

CRANIOFACIAL MORPHOLOGY - LINEAR VALUES IN MM - ANOMALY SAMPLE BEFORE TREATMENT

	male n = 31					female n = 41							
Value	Number	Min	Max	Mean	S.D.	Number	Min	Max	Mean	S.D.	Diff.	t	p
n-s	31	64.9	80.3	73.63	3.56	41	62.0	78.0	71.14	3.51	- 2.49	2.96	0.004
n-sp	31	48.3	62.2	55.54	4.23	41	46.7	62.7	54.44	3.55	- 1.10	1.19	0.240
n-gn	31	115.5	146.4	128.24	8.16	41	108.0	136.7	121.74	7.30	- 6.50	3.55	0.001
s-ba	31	41.8	55.9	48.85	3.72	41	40.3	50.9	45.87	2.75	- 2.98	3.91	0.001
s-pm	31	42.1	55.8	49.85	3.49	41	39.9	54.4	46.96	3.08	- 2.89	3.73	0.001
sp-gn	31	67.9	87.3	74.32	4.87	41	59.1	84.4	68.56	6.12	- 5.76	4.31	0.001
sp-pm	31	48.8	62.7	55.61	3.54	41	47.0	59.8	43.29	3.15	-12.32	2.92	0.005
ss-pm	31	40.5	59.0	50.07	3.59	41	42.8	55.5	48.44	3.05	- 1.63	2.08	0.041
pgn-cd	31	112.9	135.6	124.54	7.42	41	107.4	133.9	120.25	6.30	- 4.29	2.65	0.010
oj	31	-6.2	12.2	2.95	4.24	41	-3.4	9.7	2.18	3.94	- 0.77	0.80	0.430
ob	31	-6.4	3.7	-1.79	2.36	41	-5.9	2.5	-1.21	2.44	0.58	-1.03	0.310

TABLE 39

CRANIOFACIAL MORPHOLOGY - LINEAR VALUES IN MM - ANOMALY SAMPLE AFTER TREATMENT

	male n = 31					female n = 41							
Value	Number	Min	Max	Mean	S.D.	Number	Min	Max	Mean	S.D.	Diff.	t	p
n-s	31	65.7	80.5	73.92	3.64	41	61.7	78.3	71.05	3.52	-2.87	3.37	0.001
n-sp	31	45.9	65.2	56.61	4.56	41	46.5	63.8	55.17	3.64	-1.44	1.49	0.142
n-gn	31	117.7	146.6	130.80	8.01	41	108.3	137.8	124.16	6.94	-6.64	3.76	0.001
s-ba	31	41.2	55.5	48.95	3.67	41	41.8	50.8	45.97	2.65	-2.98	4.01	0.001
s-pm	31	44.2	55.6	50.35	3.37	41	41.5	54.8	47.64	2.82	-2.71	3.72	0.001
sp-gn	31	67.9	89.6	76.13	4.52	41	58.9	83.1	70.49	5.76	-5.64	4.50	0.001
sp-pm	31	47.4	62.3	55.37	3.98	41	46.3	61.4	53.08	3.06	-2.29	2.77	0.007
ss-pm	31	37.5	59.0	49.86	3.95	41	41.5	55.0	48.31	3.09	-0.55	1.87	0.066
pgn-cd	31	114.1	138.0	124.87	7.19	41	108.1	134.9	120.69	6.19	-4.18	2.64	0.010
oj	31	-5.0	11.5	3.76	3.66	41	-5.2	9.8	2.47	3.94	-1.29	1.43	0.158
ob	31	-6.6	3.6	-0.22	2.79	41	-5.2	3.5	0.08	2.49	0.14	-0.47	0.640

TABLE 40

COMPARISON OF CRANIOFACIAL LINEAR VARIABLES IN MM BETWEEN CONTROL SUBJECTS AND ANOMALY SUBJECTS BEFORE TREATMENT

Variable	Control Sample					Anomaly Sample Before Treatment							
	Number	Min	Max	Mean	S.D.	Number	Min	Max	Mean	S.D.	Diff.	t	p
n-s	36	65.8	81.9	73.96	3.579	72	62.0	80.3	72.21	3.724	-1.75	2.34	0.021
n-sp	36	44.3	56.2	53.09	3.379	72	46.7	62.7	54.91	3.870	1.82	-2.41	0.018
n-gn	36	107.1	133.1	118.92	6.591	72	108.0	146.4	124.54	8.287	5.60	-3.54	0.001
s-ba	36	38.3	50.4	45.40	3.837	72	40.3	55.9	47.16	3.510	1.76	-2.37	0.019
s-pm	36	38.7	57.1	48.58	3.852	72	39.9	55.8	48.20	3.546	-0.38	0.50	0.616
sp-gn	36	59.3	81.3	68.11	5.413	72	59.1	87.3	71.04	6.277	2.93	-2.39	0.019
sp-pm	36	46.9	61.9	54.81	3.528	72	47.0	62.7	54.29	3.497	-0.52	0.73	0.470
ss-pm	36	43.3	55.8	50.98	2.555	72	40.5	59.0	49.14	3.368	-1.84	2.89	0.005
pgn-cd	36	97.4	126.2	114.83	6.005	72	107.4	135.6	122.10	7.084	7.27	-5.28	0.001
oj	36	3.8	11.4	6.33	1.998	72	-7.4	12.2	2.51	4.058	-3.82	5.31	0.001
ob	36	-7.9	0.4	-3.96	1.617	72	-6.4	3.7	-1.46	2.404	2.50	-5.62	0.001

TABLE 41

COMPARISON OF CRANIOFACIAL LINEAR VARIABLES IN MM BETWEEN MALE CONTROL SUBJECTS AND MALE ANOMALY SUBJECTS BEFORE TREATMENT

	male control sample					male sample before treatment							
Variable	Number	Min	Max	Mean	S.D.	Number	Min	Max	Mean	S.D.	Diff.	t	p
n-s	12	69.9	81.3	73.95	3.21	31	64.9	80.3	73.63	3.56	-0.32	0.27	0.787
n-sp	12	47.1	56.2	52.66	3.13	31	48.3	62.2	55.54	4.23	2.88	-2.13	0.039
n-gn	12	110.8	127.7	118.56	5.18	31	115.5	146.4	128.24	8.16	9.68	-3.80	0.001
s-ba	12	38.3	50.3	45.93	3.22	31	41.8	55.9	48.85	3.72	2.93	-2.39	0.022
s-pm	12	43.3	57.1	49.34	3.87	31	42.1	55.8	49.85	3.49	0.51	-0.42	0.679
sp-gn	12	61.8	75.3	68.35	4.32	31	67.9	87.3	74.32	4.87	5.97	-3.72	0.001
sp-pm	12	50.9	61.9	56.56	3.54	31	48.8	62.7	55.61	3.54	-0.95	0.79	0.434
ss-pm	12	47.5	55.8	51.90	2.51	31	40.5	59.0	50.07	3.59	-1.83	1.61	0.114
pgn-cd	12	106.9	126.2	115.67	4.82	31	112.9	135.6	124.54	7.42	8.87	-3.83	0.001
oj	12	3.8	9.9	6.41	1.87	31	- 6.2	12.2	2.95	4.24	-3.46	2.71	0.010
ob	12	- 7.3	- 3.5	- 4.83	0.94	31	- 6.4	3.7	- 1.79	2.36	-3.04	-4.31	0.001

TABLE 42

COMPARISON OF CRANIOFACIAL LINEAR VARIABLES IN MM BETWEEN A SAMPLE OF FEMALE CONTROL SUBJECTS AND FEMALE ANOMALY SUBJECTS BEFORE TREATMENT

	female control sample					female sample before treatment							
Variable	Number	Min	Max	Mean	S.D.	Number	Min	Max	Mean	S.D.	Diff.	t	p
n-s	24	65.8	81.9	73.97	3.82	41	62.0	78.0	71.14	3.51	-2.83	3.04	0.003
n-sp	24	44.3	59.5	53.30	3.54	41	46.7	62.7	54.44	3.55	1.14	-1.25	0.216
n-gn	24	107.1	133.1	119.10	7.29	41	108.0	136.7	121.73	7.30	2.64	-1.41	0.164
s-ba	24	33.8	50.4	45.13	4.15	41	40.3	50.9	45.87	2.75	0.74	-0.86	0.391
s-pm	24	38.7	54.0	48.20	3.87	41	39.9	54.4	46.96	3.08	-1.24	1.42	0.160
sp-gn	24	59.3	81.3	67.99	5.97	41	59.1	84.4	68.56	6.12	0.57	-0.37	0.715
sp-pm	24	46.9	61.5	53.94	3.25	41	47.0	59.8	43.29	3.15	-10.65	0.78	0.438
ss-pm	24	43.3	55.5	50.53	2.50	41	42.8	55.5	48.44	3.05	- 2.09	2.84	0.006
pgn-cd	24	97.4	125.8	114.41	6.57	41	107.4	133.9	120.25	6.30	5.84	-3.55	0.001
oj	24	3.8	11.4	6.28	2.10	41	- 3.4	9.7	2.18	3.94	-4.10	4.72	0.001
ob	24	- 7.9	0.4	- 3.52	1.74	41	- 5.9	2.5	- 1.21	2.44	-2.31	-4.08	0.001

F) Craniofacial Morphology - Angular Dimensions

Comparison of males and females in the groupings showed very few statistically significant differences between the sets of mean variables (Tables 43,44,45). In view of the small number of these significant differences, it was concluded that it would be acceptable to combine data from the sexes when undertaking future comparisons, exercising some caution with the angle n-s-ba, which was significantly greater in females in the anomaly group.

Analysis of the comparison between the control sample and the anomaly sample before treatment revealed a high number of significant differences (see Table 46). The angle pm-s-ba was significantly ($p=0.003$) smaller in the anomaly sample, the mean difference being 3.47^{o} - this correlates with previous results in this study, showing the maxillary position to be an important cause of the decrease in nasopharyngeal space in the anomaly sample before treatment. The values s-n-sp and s-n-ss also showed significantly smaller values in the anomaly sample ($p<0.05$ and $p<0.001$) the mean differences being 1.60^{o} and 2.91^{o} respectively; this shows that the maxillary complex was less prominent in the anomaly sample when compared to the control group. Further, the angular relationship between the maxilla and mandible, ss-n-sm and ss-n-pg, both showed highly significant differences ($p<0.001$ and $p=0.017$ respectively), the anomaly sample having a smaller value with means of 3.78^{o} and 1.01^{o} respectively. The maxillary complex was thus set further back in relation to the mandible in the anomaly sample.

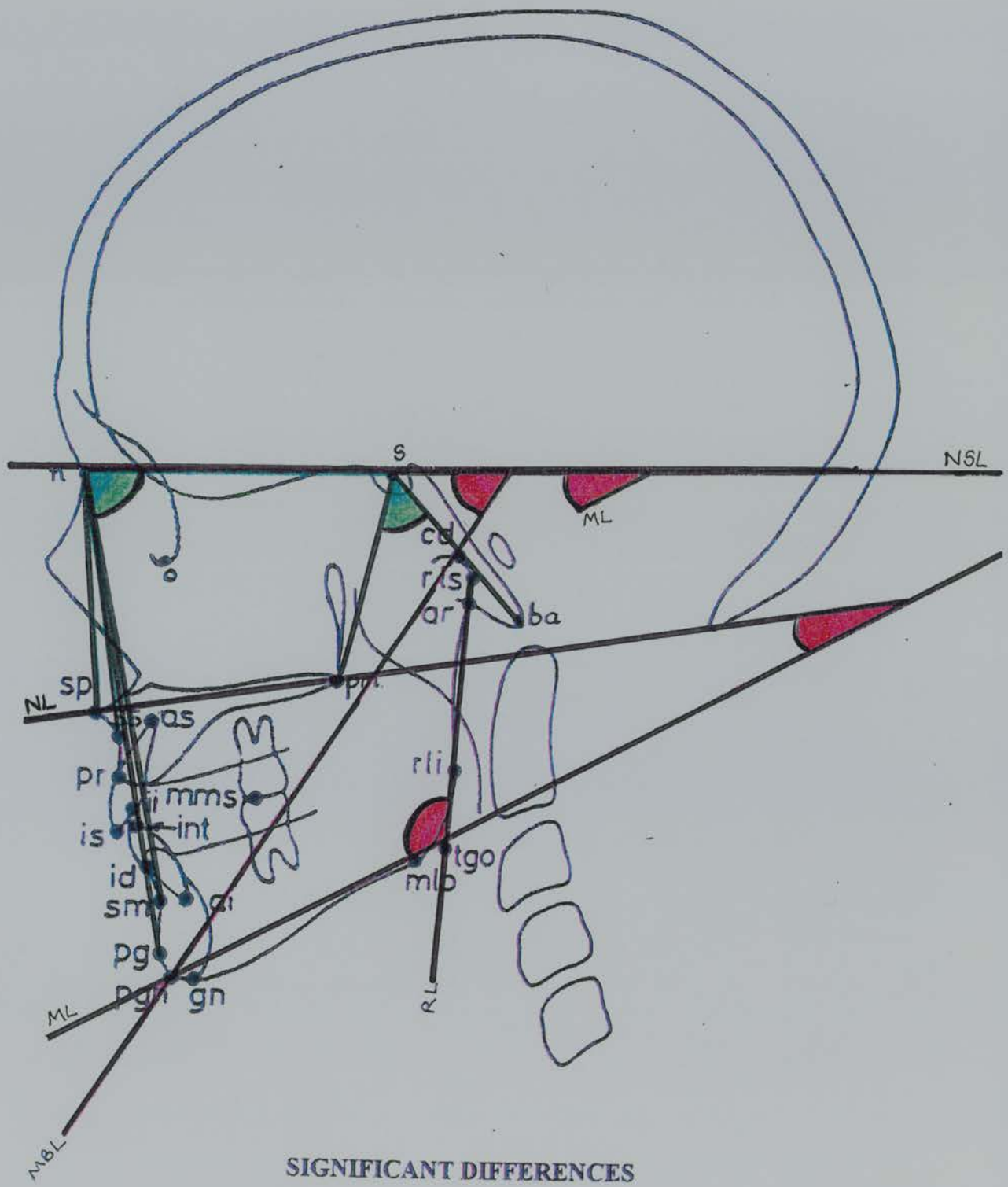
The antero-posterior position of the mandible in relation to s-n measured by the angles s-n-sm and s-n-pg, showed no significant differences.

The angle NSL/NL showed no significant difference between the two samples, indicating that the maxilla, although somewhat distal in the anomaly sample, was not tipped when measured against the control. However, the angle NSL/ML was highly significantly different ($p=0.002$); the mean value in the

anomaly group was larger by an average of 3.70°, as was the NL/ML angle ($p=0.027$), the mean value in the anomaly sample being larger by 2.44° over the control group mean.

Finally, the angles NSL/MBL and ML/RL were both significantly greater ($p<0.006$ and $p<0.000$) in the anomaly sample when compared to the control sample; the average differences were 2.78° and 4.27° respectively (see Figure 38.)

CEPHALOMETRIC ANGULAR RESULTS



SIGNIFICANT DIFFERENCES

CONTROL SAMPLE/ANOMALY SAMPLE BEFORE TREATMENT

Fig. 38

TABLE 43

CRANIOFACIAL MORPHOLOGY - ANGULAR VALUES IN DEGREES - CONTROL SAMPLE

	male n = 12					female n = 24							
Value	Number	Min	Max	Mean	S.D.	Number	Min	Max	Mean	S.D.	Diff.	t	p
n-s-ba	12	116.2	134.8	128.08	5.44	24	121.9	145.5	130.88	5.55	2.80	-1.43	0.164
pm-s-ba	12	47.8	65.0	56.91	6.10	24	50.9	70.0	54.48	6.51	-2.43	-1.14	0.263
s-n-sp	12	79.8	95.0	88.01	4.73	24	76.0	96.8	84.44	5.05	-3.57	2.04	0.051
s-n-ss	12	75.3	87.7	82.78	4.47	24	72.1	91.0	80.63	4.15	-2.15	1.43	0.163
s-n-sm	12	72.4	83.5	78.45	3.17	24	69.5	85.4	76.55	3.97	-1.90	1.44	0.164
s-n-pg	12	73.8	84.2	79.60	3.03	24	68.5	84.4	77.14	3.99	-2.46	1.87	0.071
ss-n-sm	12	0.5	9.6	4.32	2.79	24	-0.9	11.1	4.06	2.37	-0.26	0.29	0.774
ss-n-pg	12	0.4	8.1	3.30	2.54	24	0.4	9.8	3.86	2.21	0.56	-0.69	0.493

TABLE 43 (cont)

CRANIOFACIAL MORPHOLOGY - ANGULAR VALUES IN DEGREES - CONTROL SAMPLE

Value	male n = 12 Number	Min	Max	Mean	S.D.	female n = 24 Number	Min	Max	Mean	S.D.	Diff.	t	p
NSL/NL	12	1.0	13.0	6.19	3.91	24	-0.1	15.5	7.94	3.93	1.75	-1.26	0.224
NSL/ML	12	26.0	40.3	31.68	4.73	24	26.4	46.0	35.00	4.88	-3.32	-1.94	0.064
NL/ML	12	16.2	35.6	25.49	6.03	24	18.5	35.7	25.05	5.18	-0.44	-0.81	0.423
NSL/MBL	12	52.6	65.4	57.70	3.70	24	53.5	67.1	60.02	3.76	2.32	-1.79	0.092
ML/RL	12	112.0	136.4	125.45	7.03	24	116.1	138.1	125.87	6.30	0.42	-0.18	0.861

TABLE 44

CRANIOFACIAL MORPHOLOGY - ANGULAR VALUES IN DEGREES
ANOMALY SAMPLE BEFORE TREATMENT

	male n = 31					female n = 41							
Value	Number	Min	Max	Mean	S.D.	Number	Min	Max	Mean	S.D.	Diff.	t	p
n-s-ba	31	116.0	138.5	128.41	4.59	41	117.7	145.3	131.23	6.40	2.82	-2.08	0.041
pm-s-ba	31	44.5	65.5	53.85	4.76	41	45.2	71.1	56.13	5.03	2.28	-1.95	0.064
s-n-sp	31	77.0	94.4	84.66	4.46	41	74.9	90.4	83.13	3.94	-1.53	1.53	0.133
s-n-ss	31	71.1	88.8	78.98	4.31	41	72.0	86.0	78.01	3.63	-0.97	1.04	0.304
s-n-sm	31	71.2	91.4	78.06	4.90	41	67.9	89.4	78.10	4.46	0.04	-0.02	0.984
s-n-pg	31	72.8	92.8	79.00	4.58	41	69.7	90.0	78.79	4.55	-0.21	0.19	0.853
ss-n-sm	31	-5.1	6.3	0.93	3.29	41	-6.1	4.9	-0.06	2.75	-0.87	1.40	0.171
ss-n-pg	31	0.3	6.7	3.12	1.87	41	0.1	7.0	2.33	1.79	-0.79	1.81	0.070

TABLE 44 (cont)

CRANIOFACIAL MORPHOLOGY - ANGULAR VALUES IN DEGREES
ANOMALY SAMPLE BEFORE TREATMENT

	male n = 31					female n = 41							
Value	Number	Min	Max	Mean	S.D.	Number	Min	Max	Mean	S.D.	Diff.	t	p
NSL/NL	31	-2.6	13.4	7.44	3.74	41	1.4	15.9	9.49	3.76	2.05	-2.29	0.032
NSL/ML	31	19.9	46.6	37.40	6.05	41	27.1	49.9	37.73	5.86	-0.33	-0.24	0.814
NL/ML	31	18.3	40.6	29.97	5.24	41	18.1	41.1	28.24	5.29	-1.73	1.38	0.173
NSL/MBL	31	49.2	70.1	61.65	4.59	41	51.5	71.6	61.88	4.95	0.23	-0.21	0.844
ML/RL	31	118.9	139.7	130.64	5 .83	41	121.6	146.7	130.95	5.33	0.31	-0.23	0.824

TABLE 45

CRANIOFACIAL MORPHOLOGY - ANGULAR VALUES IN DEGREES
ANOMALY SAMPLE AFTER TREATMENT

	male n = 31					female n = 41							
Value	Number	Min	Max	Mean	S.D.	Number	Min	Max	Mean	S.D.	Diff.	t	p
n-s-ba	31	116.4	137.5	127.57	4.45	41	114.8	145.1	130.68	6.51	3.11	-2.29	0.025
pm-s-ba	31	45.7	65.4	53.62	4.53	41	44.3	68.3	55.97	4.99	2.35	-2.05	0.044
s-n-sp	31	75.4	94.5	84.75	4.42	41	75.6	93.7	83.55	3.91	-1.20	1.22	0.227
s-n-ss	31	70.0	88.0	79.07	4.21	41	72.0	88.5	78.48	3.67	-0.59	0.63	0.531
s-n-sm	31	71.3	88.6	77.28	4.51	41	67.7	88.8	77.58	4.52	0.30	-0.28	0.782
s-n-pg	31	71.9	89.9	78.19	4.27	41	69.1	89.5	78.13	4.67	-0.06	0.06	0.954
ss-n-sm	31	-5.6	7.8	1.78	3.43	41	-5.7	6.1	0.90	3.12	-0.88	1.13	0.262
ss-n-pg	31	0.3	7.8	3.38	1.92	41	0.1	7.4	2.85	1.71	-0.53	1.85	0.216

TABLE 45 (cont)

CRANIOFACIAL MORPHOLOGY - ANGULAR VALUES IN DEGREES
ANOMALY SAMPLE AFTER TREATMENT

	male n = 31					female n = 41							
Value	Number	Min	Max	Mean	S.D.	Number	Min	Max	Mean	S.D.	Diff.	t	p
NSL/NL	31	-0.3	16.9	8.24	3.87	41	0.8	15.5	9.76	3.72	1.52	-1.68	0.097
NSL/ML	31	22.8	47.6	38.55	6.55	41	27.5	52.8	39.08	6.08	0.53	-0.36	0.722
NL/ML	31	17.4	41.4	30.33	5.79	41	16.2	42.1	29.32	5.45	-1.01	0.76	0.452
NSL/MBL	31	52.0	70.7	62.77	4.88	41	51.6	73.7	62.79	5.15	0.02	-0.01	0.990
ML/RL	31	119.3	138.9	130.64	6.03	41	123.3	146.8	131.32	5.34	0.68	-0.51	0.613

TABLE 46

A COMPARISON OF CRANIOFACIAL ANGULAR VALUES IN DEGREES BETWEEN THE CONTROL SUBJECTS AND THE ANOMALY SUBJECTS BEFORE TREATMENT

Variable	Control Sample					Anomaly Sample Before Treatment							
	Number	Min	Max	Mean	S.D.	Number	Min	Max	Mean	S.D.	Diff.	t	p
n-s-ba	36	116.2	145.5	129.95	5.594	72	116.0	145.3	130.01	5.828	0.06	-0.06	0.956
pm-s-ba	36	47.8	70.0	58.62	6.409	72	44.5	71.1	55.15	5.013	-3.47	3.09	0.003
s-n-sp	36	76.0	96.8	85.63	5.164	72	74.9	94.4	83.79	4.213	-1.60	1.98	0.050
s-n-ss	36	72.1	91.0	81.34	4.318	72	71.1	88.8	78.43	3.940	-2.91	3.51	0.001
s-n-sm	36	69.5	85.4	77.18	3.789	72	67.9	91.4	78.07	4.622	0.89	-1.00	0.318
s-n-pg	36	68.5	84.4	77.96	3.840	72	69.7	92.8	78.88	4.530	0.92	-1.04	0.299
ss-n-sm	36	-0.9	11.1	4.14	2.482	72	-6.1	6.3	0.36	3.016	-3.78	6.50	0.001
ss-n-pg	36	0.4	9.8	3.68	2.301	72	0.1	7.0	2.67	1.857	-1.01	2.44	0.017
NSL/NL	36	-0.1	15.5	7.36	3.953	72	- 2.6	15.9	8.61	3.863	1.25	-1.57	0.119
NSL/ML	36	26.0	46.0	33.89	5.023	72	19.9	49.9	37.59	5.903	3.70	-3.22	0.002
NL/ML	36	16.2	35.7	26.54	5.438	72	18.1	41.1	28.98	5.303	2.44	-2.24	0.027
NSL/MBL	36	52.6	67.1	59.24	3.846	72	49.2	71.6	61.79	4.764	2.55	-2.78	0.006
ML/RL	36	112.0	138.1	125.73	6.455	72	118.9	146.7	130.82	5.512	5.09	-4.27	0.001

G) Correlations

The relationship between head posture, craniocervical angulation and craniofacial morphology was the subject of a hypothesis suggested by Solow and Kreiborg (1977) (see Figure 1). It was suggested that subjects exhibiting increased nasal airway resistance extended the head in relation to the cervical column in order to maintain their vital airway adequacy. This head extension led in turn to stretching of the facial soft tissues, resulting in differential forces on the facial skeleton with consequent effect on craniofacial growth. The net result was the "adenoidal facies".

An analysis of the correlation between specific variables relating to anterior facial height and head posture reveals a comprehensive pattern of associations in the anomaly sample before treatment (see Table 48.) The head posture variables NSL/CVT and NSL/OPT showed positive associations with upper facial height n-sp, lower facial height sp-gn and NL/ML, the angular measurement of lower facial height. Hence a large facial height was seen with a large craniofacial angulation.

Negative associations were seen in the anomaly sample before treatment and in the control sample between the head posture variables and the measurements of airway adequacy pm-ad_1 and pm-ad_2. Hence the larger the head posture variables, the smaller the airway dimension value.

It would appear, therefore, that the present study goes a considerable way to supporting the Solow and Krieborg (1977) control system hypothesis.

TABLE 47

CORRELATIONS

CONTROL SAMPLE N = 36

	Facial morphology			Head posture		Airway dimensions				Nasal resistance		Width	
												Maxilla	Nasal
	n-sp	sp-gn	NL/ML	NSL/CVT	NSL/OPT	pm-ad$_1$	pm-ad$_2$	pm-ad$_3$	tu-ad$_3$	PNR (I)	PNR (E)	CNR/CML	EMR/EML
n-sp										-0.36*	-0.35*		0.39*
sp-gn			0.59**										
NL/ML		0.59**											
NSL/CVT					0.94**								
NSL/OPT				0.94**									
pm-ad$_1$							0.80**						-0.32*
pm-ad$_2$					-0.39*	0.80*		0.56**					
pm-ad$_3$							0.56**						
tu-ad$_3$													
PNR (I)	-0.36*										0.98**		
PNR (E)	-0.35*									0.98**			
CNR/CNL													0.33*
EMR/EML	0.39*											0.33*	

* p < .05
** p < .01

CORRELATIONS

TABLE 48

ANOMALY SAMPLE BEFORE TREATMENT N = 72

	Facial morphology			Head posture		Airway dimensions				Nasal resistance		Width	
												Maxilla	Nasal
	n-sp	sp-gn	NL/ML	NSLCVT	NSL/OPT	pm-ad$_1$	pm-ad$_2$	pm-ad$_3$	tu-ad$_3$	PNR(I)	PNR(E)	CNR/CNL	EMR/EML
n-sp	.	0.36**	.	0.35**	0.39**	.	.	.	.	.	.	.	.
sp-gn	0.36**	.	0.62**	0.25*	0.32**	.	.	0.29*	.	.	.	.	.
NL/ML	.	0.62**	.	0.43**	0.41**	.	.	.	.	.	.	.	.
NSL/CVT	.	.	.	.	.	.	.	.	.	.	.	.	.
NSL/OPT	0.39**	0.32**	0.41**	0.95**	.	-0.31**	-0.37**	.	.	.	.	.	.
pm-ad$_1$	.	.	.	-0.31**	-0.31**	.	0.86**	0.36**	0.24**	.	.	.	.
pm-ad$_2$	.	.	.	-0.36**	-0.37**	0.86**	.	0.52**	0.32**	.	.	.	.
pm-ad$_3$	.	0.29*	.	.	.	0.36**	0.52**	.	.	.	.	.	0.40**
tu-ad$_3$	.	.	.	.	.	0.24*	0.32**	.	.	.	.	.	.
PNR(I)	.	.	.	.	.	.	.	.	.	.	0.99**	.	.
PNR(E)	.	.	.	.	.	.	.	.	.	0.99**	.	.	.
CNR/CNL	.	.	.	.	.	.	.	.	.	.	.	.	0.49**
EMR/EML	.	.	.	-0.27*	-0.29*	.	.	0.40**	.	.	.	0.49**	.

* p <0.5
**p <0.1

5.2 CHANGES IN THE ANOMALY SAMPLE WITH TREATMENT

A) Nasal Airway Resistance

Comparisons of the mean rhinomanometric variables between males and females in the anomaly sample after treatment (see Tables 19 and 20) showed only four statistically significant differences ($p<0.05$) out of a total of eighteen separate comparisons. It was therefore concluded that it would be reasonable to combine the data for the sexes in this group.

Total upper airway resistance

The changes in the rhinomanometric values of the anomaly sample are shown in Table 49,50. As far as the total upper airway values are concerned, the anomaly sample before treatment showed a mean value of 468.76 for inspiration, against the anomaly sample after treatment value of 395.44, a reduction of 73.32. This is a significant difference at the $p<0.001$ level, as is the total expiratory mean value of 459.97 for the anomaly sample before treatment compared with 375.67 for the sample after treatment, a reduction of 84.30. (see Fig.39)

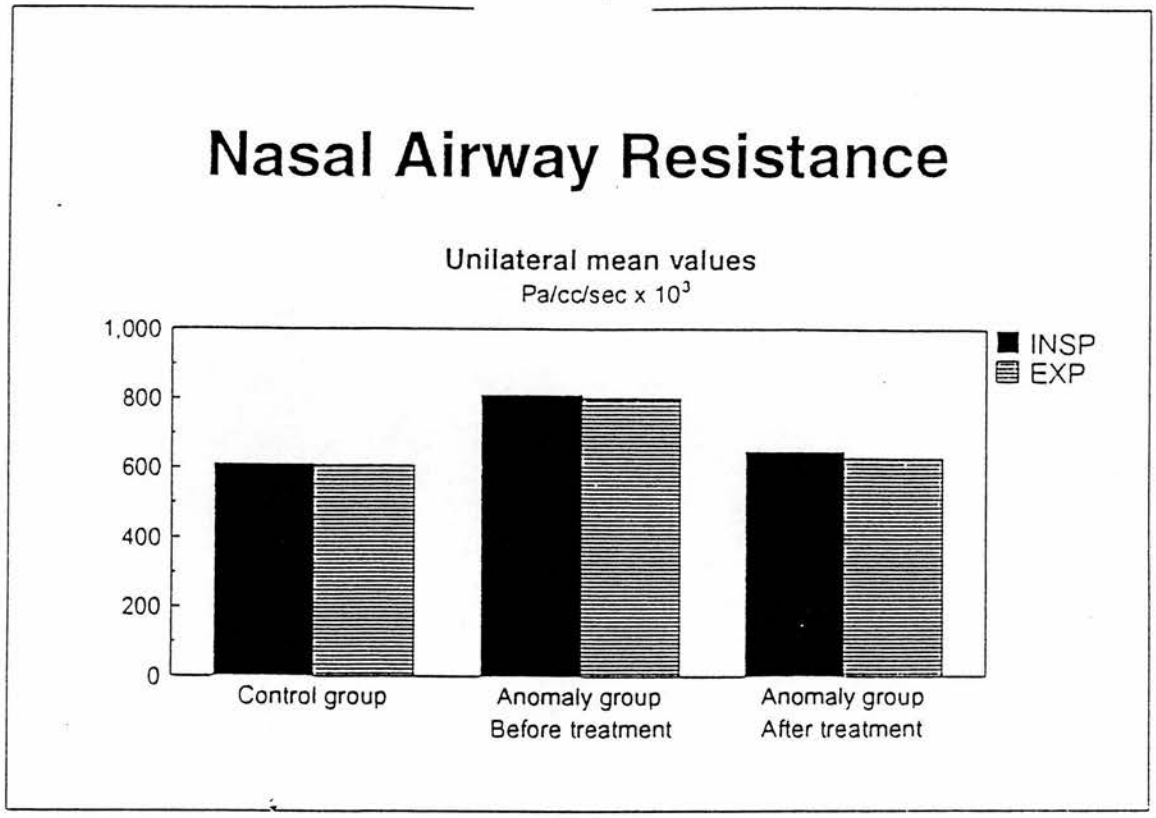
The change in the total laminar (K_1) value for inspiration was from 196.84 for the anomaly sample before treatment to 130.29 after treatment, a reduction of 66.55 ($p<0.001$) and for the expiratory (K_1) laminar flow value from 186.53 before treatment to 123.16 after treatment, a reduction of 63.37 ($p<0.001$). The change in the mean turbulent (K_2) flow value for inspiration was from 714.85 before treatment to 482.47 after treatment - a reduction of 232.38 ($p<0.001$): for expiration the mean was 710.56 before treatment compared with a mean of 490.81 after treatment; a reduction of 219.75 ($p<0.001$). (Fig.40)

Unilateral nasal airway resistance

As can be seen from Table 49 the mean differences in NAR in the anomaly sample before and after treatment are all highly significant at the $p<0.001$ level, with the mean values after treatment being the lower in each case. The mean values of the resistance before treatment varied from 819.48 pascals/cc/second x 10^3 for NR R EXP to 827.98 pascals/cc/second x 10^3 for NR R INS. The mean values for the resistance after treatment varied from 631.68 pascals/cc/second x 10^3 for NA R EXP to 656.69 pascals/cc/second x 10^3 for NA L INS.(see Fig.39)

For laminar flow values (K_1) and turbulent flow values (K_2) (see Table 50) the mean differences were also seen to be highly statistically significant at the $p<0.001$ level. The laminar flow values before treatment ranged from 239.43 for K_1 L EXP to 267.27 for K_1 R INS. The mean laminar flow values after treatment varied from 165.66 for K_1 L EXP to 188.05 for K_1 R INS.

The mean turbulent flow values before treatment ranged from 1233.87 for K_2 R EXP to 1328.92 for K_2 L INS. After treatment the range was from 888.91 for K_2 R EXP to 1012.80 for K_2 L INS.(see Fig.40)


Nasal Airway Resistance
Unilateral mean values
Pa/cc/sec x 10³
1,000
800
600
400
200
0
INSP
EXP
Control group
Anomaly group
Before treatment
Anomaly group
After treatment

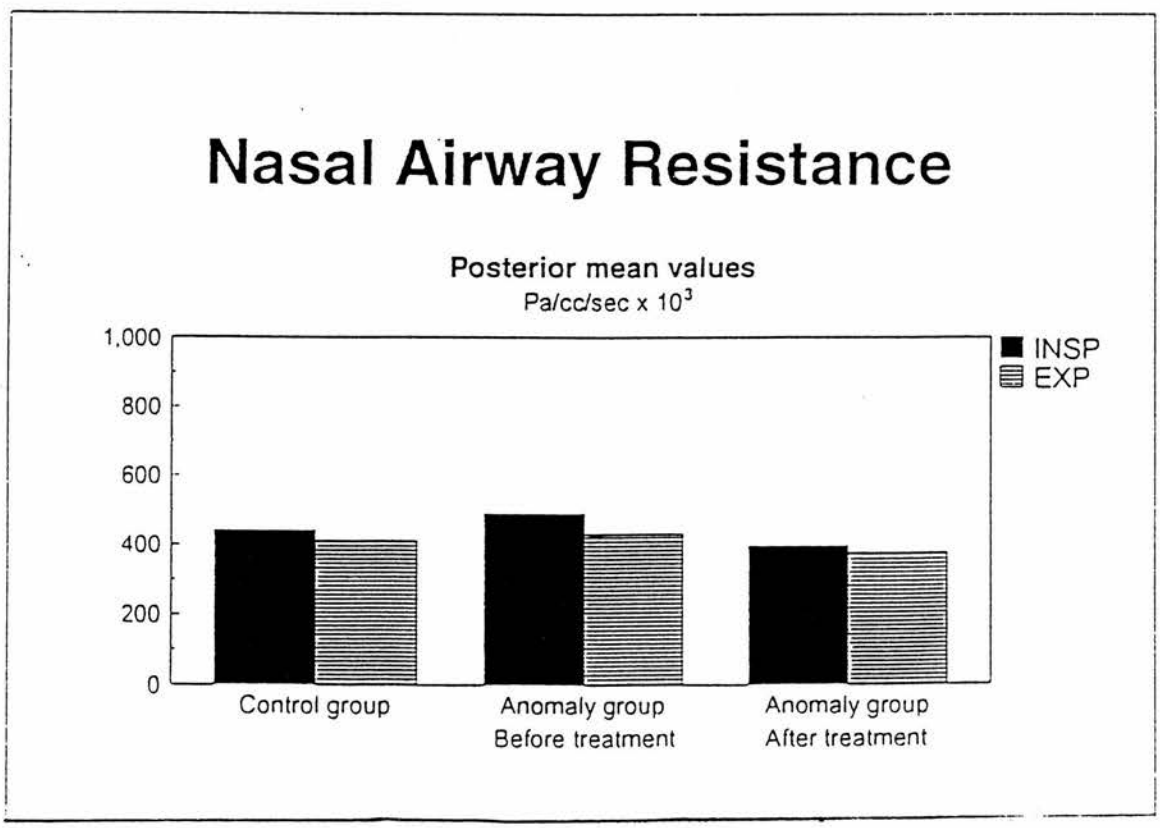
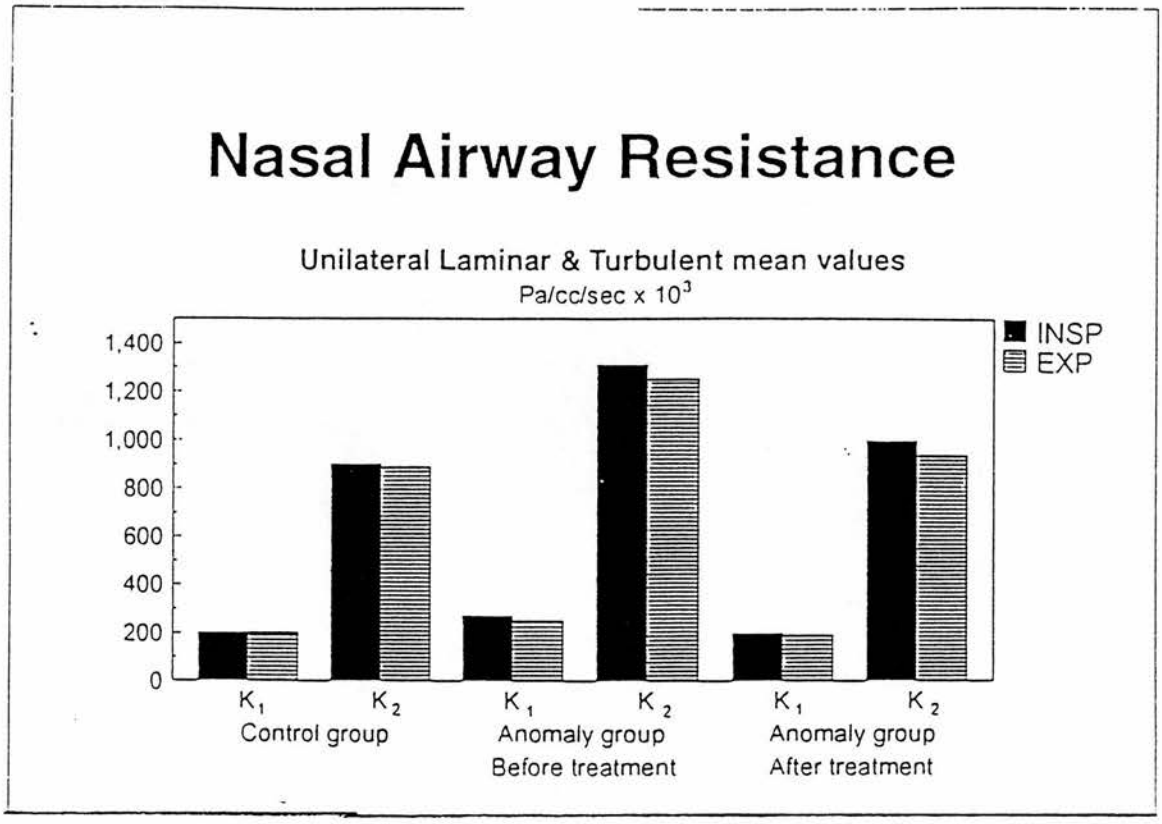

Nasal Airway Resistance
Posterior mean values
Pa/cc/sec x 10³
1,000
800
600
400
200
0
INSP
EXP
Control group
Anomaly group
Before treatment
Anomaly group
After treatment

Fig. 39


Nasal Airway Resistance
Unilateral Laminar & Turbulent mean values
Pa/cc/sec x 10³
1,400
1,200
1,000
800
600
400
200
0
INSP
EXP
K₁
K₂
Control group
Anomaly group
Before treatment
Anomaly group
After treatment

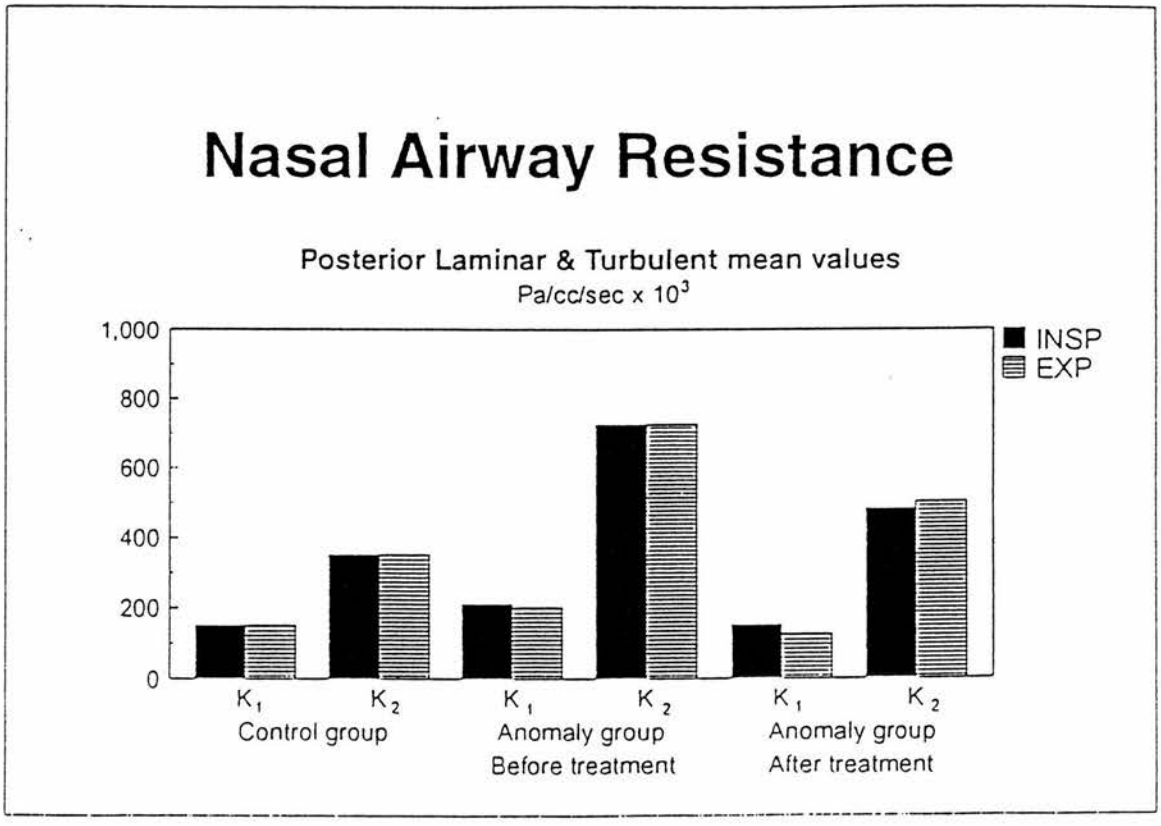

Nasal Airway Resistance
Posterior Laminar & Turbulent mean values
Pa/cc/sec x 10³
1,000
800
600
400
200
0
INSP
EXP
K₁
K₂
Control group
Anomaly group
Before treatment
Anomaly group
After treatment

Fig. 40

TABLE 49

NASAL AIRWAY RESISTANCE: TREATMENT CHANGES IN ANOMALY SAMPLE
N A R (pascal/cc/sec x 10^3) at 150 pascals

Variable	Anomaly Before					Anomaly After							
	Number*	Min	Max	Mean	S.D.	Number*	Min	Max	Mean	S.D.	Diff.	t	p
ANT L													
INSP	57	460	1746	827.89	230.66	57	411	996	656.69	140.68	-171.20	7.18	0.001
EXP	57	425	1668	825.47	227.54	57	410	957	637.11	139.07	-188.36	7.71	0.001
ANT R													
INSP	55	447	1565	827.98	227.77	55	356	1037	644.17	144.99	-183.88	6.78	0.001
EXP	55	438	1514	819.48	229.08	55	335	1069	631.68	154.76	-187.80	6.80	0.001
POST													
INSP	58	302	971	468.76	147.27	58	249	883	395.44	108.79	-73.32	4.68	0.001
EXP	58	293	900	459.97	140.29	58	222	851	375.67	106.03	-84.30	4.50	0.001

* The numbers vary because certain subjects were unable to complete all the tests

TABLE 50

NASAL AIRWAY RESISTANCE: TREATMENT CHANGES IN ANOMALY SAMPLE

Laminar and Turbulent flow coefficients K1/K2 (pascal/cc/sec x 10^3) at 150 pascals

Variable	Before Treatment Number*	Min	Max	Mean	S.D.	After Treatment Number*	Min	Max	Mean	S.D.	Diff.	t	p
ANT L													
INSP K_1	59	120	593	257.30	88.08	59	100	295	176.82	44.77	-80.48	7.56	0.001
EXP K_1	59	110	410	239.43	74.52	59	93	246	165.66	41.27	-73.77	7.93	0.001
ANT R													
INSP K_1	55	110	876	267.27	121.49	55	112	372	188.05	57.89	-79.22	4.17	0.001
EXP K_1	55	108	848	256.80	117.09	55	105	368	180.47	55.13	-76.33	3.97	0.001
POST													
INSP K_1	58	102	484	196.84	82.21	58	62	259	130.29	44.71	-66.55	5.83	0.001
EXP K_1	58	97	478	186.53	82.73	58	56	220	123.16	40.52	-63.37	5.44	0.001
ANT L													
INSP K_2	59	452	1933	1328.92	314.61	59	471	1841	1012.80	311.98	-316.12	7.41	0.001
EXP K_2	59	447	1934	1276.59	315.42	59	512	1773	981.09	300.13	-295.50	7.27	0.001
ANT R													
INSP K_2	55	374	1907	1297.61	365.70	55	374	1854	941.68	362.25	-355.93	6.55	0.001
EXP K_2	55	397	1887	1233.87	360.98	55	343	1752	888.91	351.19	-344.96	6.44	0.001
POST													
INSP K_2	58	177	1571	714.85	318.01	58	132	1060	482.47	193.52	-232.38	5.59	0.001
EXP K_2	58	176	1512	710.56	319.51	58	116	1040	490.81	194.61	-219.75	5.09	0.001

* The numbers vary because certain subjects were unable to complete all the tests

B) Transverse Craniofacial Dimensions

These results will be presented in two ways; first, with the sexes considered separately and, second, a comparison of the changes to the combined sex anomaly sample.

(i) Sexes considered separately

When the variables relating to the two sexes were compared in the anomaly sample after treatment (see Table 25), a number of changes showed significant differences between the mean values for males and females. It was thought that this may indicate a different response by males and females to the process of rapid maxillary expansion, so comparisons were made (see Tables 52 and 53) between male subjects before and after treatment and, separately, female subjects before and after treatment.

On analysis of the results, however, the male and female groups both largely followed the same trend as indicated by the combined results table (Table 51), so the existence of a fundamental difference between males and females in the reaction to rapid palatal expansion could not be shown.

(ii) Sexes combined

When the comparison was made of the mean postero-anterior cephalometric variables in the anomaly sample before treatment and after treatment (see Table 51), several statistically significant differences were found (see Figure 41).

The total mean width in mm of the anterior nasal base CNR-CNL was significantly larger ($p<0.001$) in the sample after treatment, by about 10.5%. When this measurement is broken down into right side (CNR-CNM) and left side (CNM-CNL) both are found to be significant at the $p<0.001$ level, the right side showing an increase of 7.8%, the left 8.9%. (The apparent discrepancy of the upper left and right sides increasing by some 8%, whilst the total width increases by 10%, reflects the problem of accurately measuring the right and left components.)

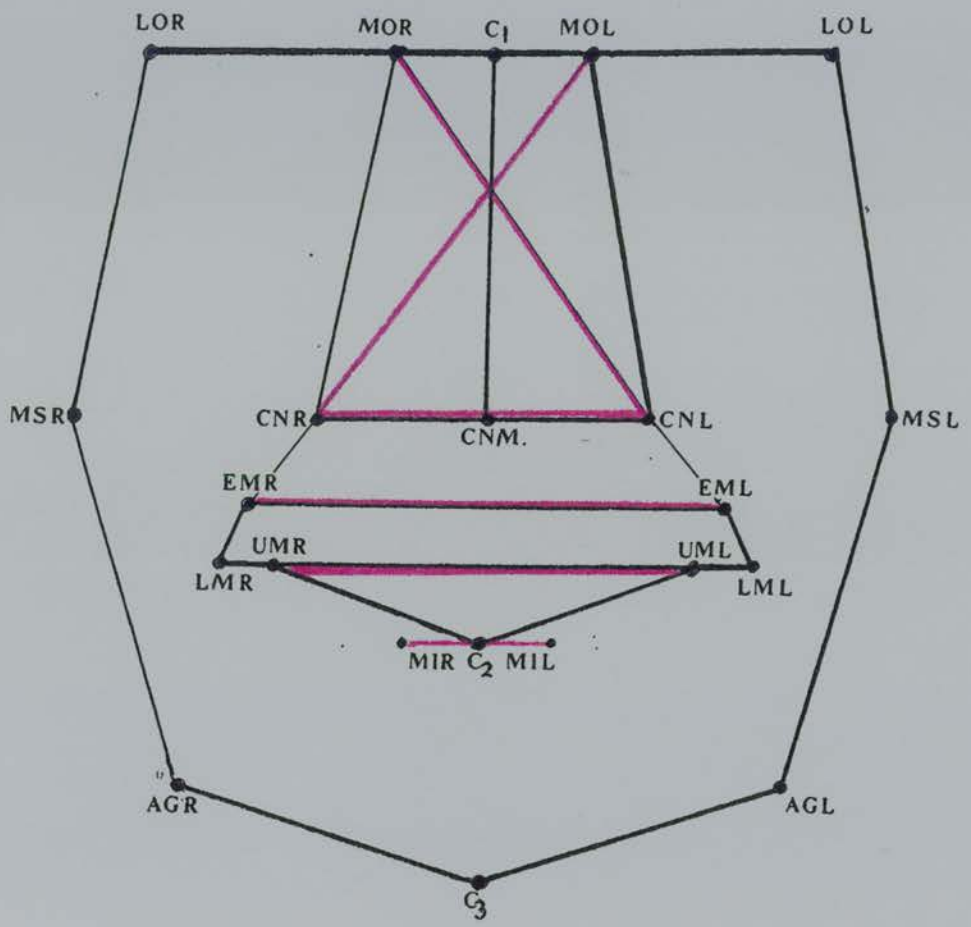
The maxillary box width EMR-EML was significantly increased ($p < 0.001$) after treatment in both males and females, a 3.5% difference, whereas the distances between the buccal surfaces of the maxillary first molars UMR-UML increased by 14.5%, significant at the $p < 0.001$ level in both males and females.

The total width in mm between the buccal surfaces of the lower first molars, LMR-LML, also increased significantly overall after treatment ($p < 0.002$) (Table 51).

The distance in m.m. between the mesial surfaces of the two upper central incisors, MIR-MIL before and after treatment, showed a highly significant difference ($p < 0.001$), as did the breakdown of the two subsections MIR-C_2 and C_2-MIL ($p < 0.001$).

Finally, the nasal proportion NAS DIM showed an increase of 3.75% after treatment with RME - significant at the $p < 0.001$ level.

POSTERO ANTERIOR CEPHALOMETRIC RESULTS



SIGNIFICANT DIFFERENCES

ANOMALY SAMPLE BEFORE/AFTER TREATMENT

Fig. 41

TABLE 51

CHANGES IN TRANSVERSE CEPHALOMETRIC DIMENSIONS IN MM WITH TREATMENT OF ANOMALY SAMPLE

Variable	Anomaly Sample Before Treatment					Anomaly Sample After Treatment							
	Number	Min	Max	Mean	S.D.	Number	Min	Max	Mean	S.D.	Diff.	t	p
CNR-CNM	72	12.80	19.90	15.85	1.700	72	14.60	21.50	17.08	1.495	1.23	- 8.41	0.001
CNM-CNL	72	11.90	20.00	15.46	1.670	72	11.60	20.80	16.84	1.650	1.38	- 9.71	0.001
CNR-CNL	72	20.20	35.00	28.00	2.948	72	24.50	37.50	30.96	2.851	2.96	-17.93	0.001
EMR-EML	72	51.50	68.80	60.99	4.271	72	54.40	76.60	63.14	4.041	2.15	- 8.14	0.001
UMR-UML	72	44.20	66.20	53.86	4.579	72	50.20	72.50	61.63	4.578	7.77	-18.35	0.001
LMR-LML	72	44.40	70.70	58.45	4.340	72	44.50	70.80	58.80	4.303	0.35	- 3.18	0.002
MIR-MIL	72	0.00	5.30	0.38	0.991	72	2.30	8.20	5.13	1.536	4.75	-23.07	0.001
MIR-C2	72	0.00	2.40	0.19	0.418	72	1.10	3.90	2.46	0.796	2.27	-22.12	0.001
C2-MIL	72	0.00	3.40	0.21	0.577	72	1.10	4.30	2.67	0.787	2.46	-22.70	0.001
NAS-DIM	72	55.50	79.50	66.99	5.258	72	56.00	82.50	69.49	5.732	2.50	6.36	0.001
MAX -DIM	72	68.40	89.50	78.31	5.373	72	68.00	90.30	78.61	5.238	0.30	0.79	0.433

TABLE 52

CHANGES IN TRANSVERSE CEPHALOMETRIC DIMENSIONS IN MM WITH TREATMENT MALE ANOMALY SAMPLE

Variable	Before Treatment					After Treatment							
	Number	Min	Max	Mean	S.D.	Number	Min	Max	Mean	S.D.	Diff.	t	p
CNR-CNM	31	12.80	19.5	16.23	1.76	31	14.7	21.5	17.41	1.58	+0.82	-4.59	0.001
CNM-CNL	31	11.90	20.0	15.92	1.88	31	14.4	20.8	17.22	1.48	+1.25	-5.37	0.001
CNR-CNL	31	23.10	35.0	28.75	2.98	31	24.5	37.3	31.51	2.72	+2.76	-10.21	0.001
EMR-EML	31	53.60	68.8	62.65	4.19	31	56.9	76.6	64.60	4.51	+1.95	-4.58	0.001
UMR-UML	31	44.20	66.2	54.93	4.99	31	51.7	72.5	62.93	5.44	+8.00	-12.57	0.001
LMR-LML	31	48.90	70.7	59.70	4.30	31	49.9	70.8	60.05	4.29	+0.35	-2.18	0.038
MIR-MIL	31	0.00	5.3	0.58	1.38	31	2.7	7.7	5.54	1.49	+4.96	-15.18	0.001
MIR-C2	31	0.00	2.4	0.27	0.58	31	1.1	3.9	2.69	0.76	+2.42	-15.12	0.001
C2-MIL	31	0.00	3.4	0.34	0.81	31	1.5	4.2	2.85	0.77	+2.51	-14.51	0.001
NAS-DIM	31	58.30	79.0	67.67	4.59	31	58.3	82.5	70.18	5.11	+2.51	3.84	0.001
MAX-DIM	31	68.40	86.8	78.13	4.67	31	68.0	90.3	78.28	5.06	+0.15	0.24	0.815

TABLE 53

CHANGES IN TRANSVERSE CEPHALOMETRIC DIMENSIONS IN MM WITH TREATMENT FEMALE ANOMALY SAMPLE

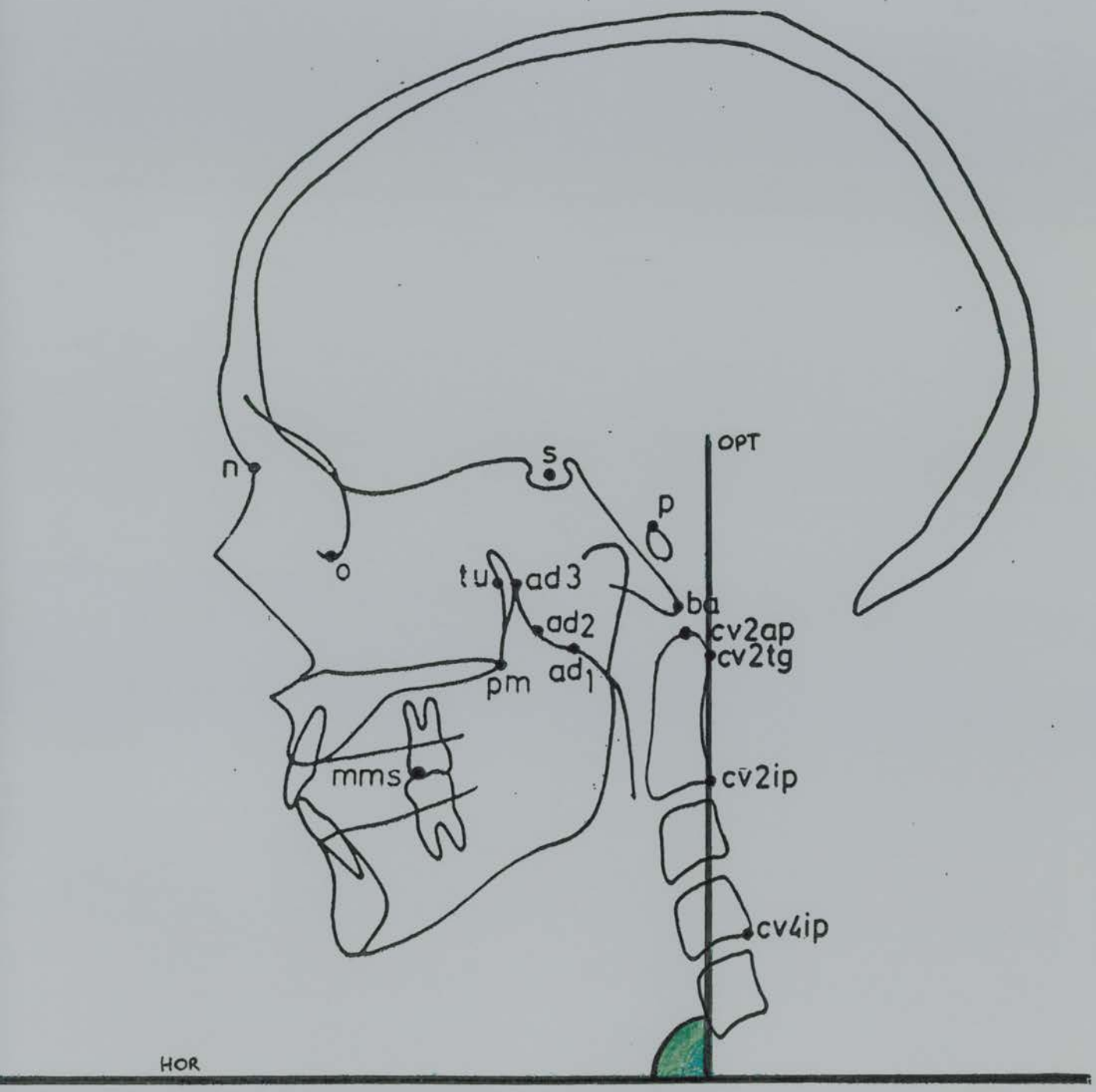
Variable	Before Treatment					After Treatment							
	Number	Min	Max	Mean	S.D.	Number	Min	Max	Mean	S.D.	Diff.	t	p
CNR/CNM	41	12.90	19.90	15.48	1.65	41	14.60	20.20	16.75	1.41	+1.27	-7.43	0.001
CNM-CNL	41	12.50	18.10	14.94	1.46	41	11.60	20.20	16.45	1.82	+1.51	-8.29	0.001
CNR-CNL	41	20.20	33.00	27.44	2.83	41	25.00	37.50	30.55	2.91	+3.11	-15.15	0.001
EMR-EML	41	51.50	67.80	59.74	3.93	41	54.40	71.00	62.03	3.29	+2.29	-6.85	0.001
UMR-UML	41	44.20	60.20	53.05	4.12	41	50.20	71.00	62.03	3.29	+7.59	-13.27	0.001
LMR-LML	41	44.40	67.24	57.51	4.17	41	44.50	68.10	57.86	4.11	+0.35	-2.31	0.026
MIR-MIL	41	0.00	2.30	0.22	0.51	41	2.30	8.20	4.82	1.51	+4.60	-17.33	0.001
MIR-C2	41	0.00	1.20	0.13	0.23	41	1.10	3.90	2.29	0.78	+2.16	-16.29	0.001
C2-MIL	41	0.00	1.40	0.12	0.29	41	1.10	4.30	2.54	0.78	+2.42	-17.32	0.001
NAS-DIM	41	55.50	79.50	66.48	5.71	41	56.00	82.00	68.97	0.89	+2.49	5.10	0.001
MAX-DIM	41	69.10	89.50	78.45	5.90	41	69.00	80.00	78.87	5.42	+0.42	0.88	0.382

C) Head Posture

The changes between the values before and after treatment (see Table 54) were not statistically significant. On examining the three variables previously described, NSL/VER shows a reduction between the means of 0.47 of one degree, NSL/OPT an increase of 0.78 of one degree between the means and NSL/CVT an increase of 0.57 of one degree between the means before and after treatment. All of these differences are negligible.

Only the variable OPT/HOR, however, the cervical inclination, showed a significantly smaller value after treatment with RME ($p=0.032$), the value decreasing from 85.28^{o} to 84.03^{o}, a difference of 1.25^{o}. This difference represents a slight forward tipping of the cervical inclination after treatment (see Figure 42).

HEAD POSTURE RESULTS



SIGNIFICANT DIFFERENCES

ANOMALY SAMPLE BEFORE/AFTER TREATMENT

Fig. 42

TABLE 54

CHANGES IN HEAD POSTURE IN DEGREES WITH TREATMENT

Variable	Anomaly Before					Anomaly After							
	Number	Min	Max	Mean	S.D.	Number	Min	Max	Mean	S.D.	Diff.	t	p
NSL/VER	72	79.4	109.2	96.69	6.22	72	83.2	109.2	96.22	5.75	-0.47	0.82	0.416
NL/VER	72	64.0	100.5	87.81	6.63	72	71.0	98.0	86.86	5.65	-0.95	1.67	0.099
NSL/OPT	72	80.6	119.0	101.41	8.89	72	80.6	124.4	102.19	8.75	0.78	-1.19	0.237
NSL/CVT	72	83.1	123.6	105.47	8.43	72	84.8	128.0	106.04	8.35	0.57	-0.89	0.377
NL/OPT	72	72.8	108.7	92.80	8.32	72	77.6	111.1	93.09	7.89	0.29	-0.44	0.661
NL/CVT	72	77.8	113.2	96.85	7.87	72	82.2	114.7	96.93	7.49	0.08	-0.12	0.904
OPT/HOR	72	71.8	102.8	85.28	7.07	72	68.8	106.0	84.03	7.61	-1.25	2.19	0.032
CVT/HOR	72	65.9	99.0	81.23	6.6.3	72	65.1	100.3	80.18	6.65	-1.05	1.97	0.052
FH/VER	72	70.0	104.1	85.63	6.49	72	72.8	96.4	85.26	5.59	-0.37	0.62	0.536
FH/OPT	72	70.3	104.3	90.35	8.34	72	72.3	107.1	91.23	7.98	0.88	-1.32	0.192
FH/CVT	72	74.4	109.2	94.39	7.63	72	76.5	110.5	95.08	7.39	0.69	-1.03	0.304

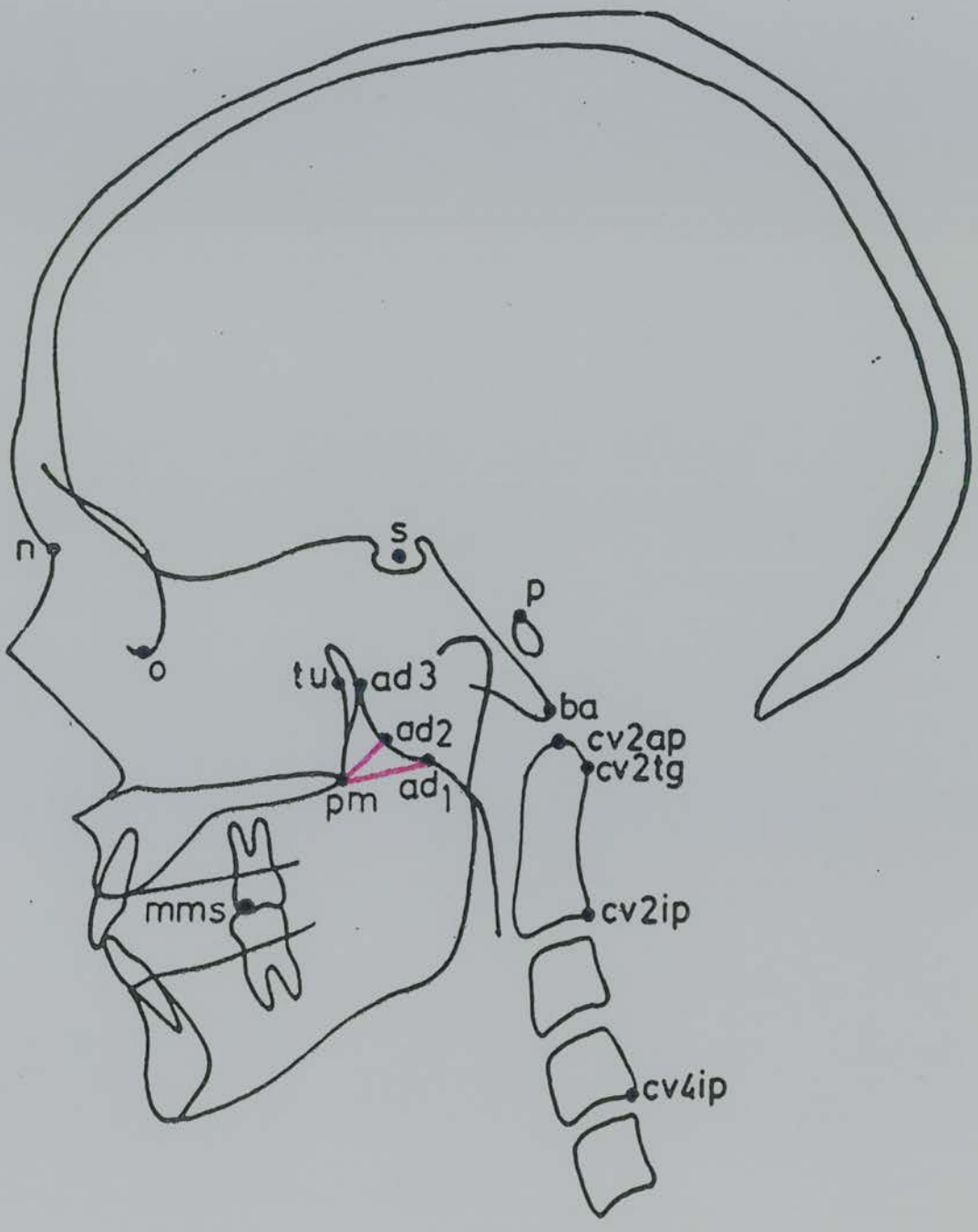
D) Airway Dimensions

Two variables, pm-ad$_1$ and pm-ad$_2$, showed highly significant changes with treatment ($p < 0.001$) (see Table 55 and Figure 43).

The mean of pm-ad$_1$ was increased by 1.51mm, representing an increase in dimension of 8.33%. The value of pm-ad$_2$ was increased by 0.76mm, representing a 5.43% change.

The other two variables pm-ad$_3$ and tu-ad$_3$ showed no significant changes, whether the values were gender pooled or whether males and females were considered separately (Tables 56,57).

AIRWAY DIMENSION RESULTS



SIGNIFICANT DIFFERENCES

ANOMALY SAMPLE BEFORE/AFTER TREATMENT

Fig. 43

TABLE 55

CHANGES IN AIRWAY DIMENSIONS IN MM WITH TREATMENT

Variable	Anomaly Before Treatment					Anomaly After Treatment							
	Number	Min	Max	Mean	S.D.	Number	Min	Max	Mean	S.D.	Diff.	t	p
$pm\text{-}ad_1$	72	4.6	29.2	18.12	5.359	72	7.5	28.9	19.63	5.467	1.51	-3.91	0.001
$pm\text{-}ad_2$	72	4.6	22.0	13.98	4.078	72	6.5	22.1	14.74	3.636	0.76	-3.34	0.001
$pm\text{-}ad_3$	72	15.3	32.3	23.75	3.083	72	12.9	31.0	23.93	3.122	0.18	-0.78	0.436
$tu\text{-}ad_3$	72	3.2	12.3	6.92	1.88	72	3.6	13.0	7.12	1.709	0.20	-1.02	0.309

TABLE 56

CHANGES IN AIRWAY DIMENSIONS IN MM OF THE MALE ANOMALY SUBJECTS WITH TREATMENT

Variable	Anomaly Sample Before Treatment					Anomaly Sample After Treatment							
	Number	Min	Max	Mean	S.D.	Number	Min	Max	Mean	S.D.	Diff.	t	p
pm-ad_3	31	20.1	32.3	24.74	2.33	31	21.1	31.0	24.96	2.46	0.22	-0.62	0.543
tu-ad_3	31	3.2	9.6	6.90	1.59	31	5.0	13.0	7.24	1.69	0.34	-1.01	0.320

TABLE 57

CHANGES IN AIRWAY DIMENSIONS IN MM OF THE FEMALE ANOMALY SUBJECTS WITH TREATMENT

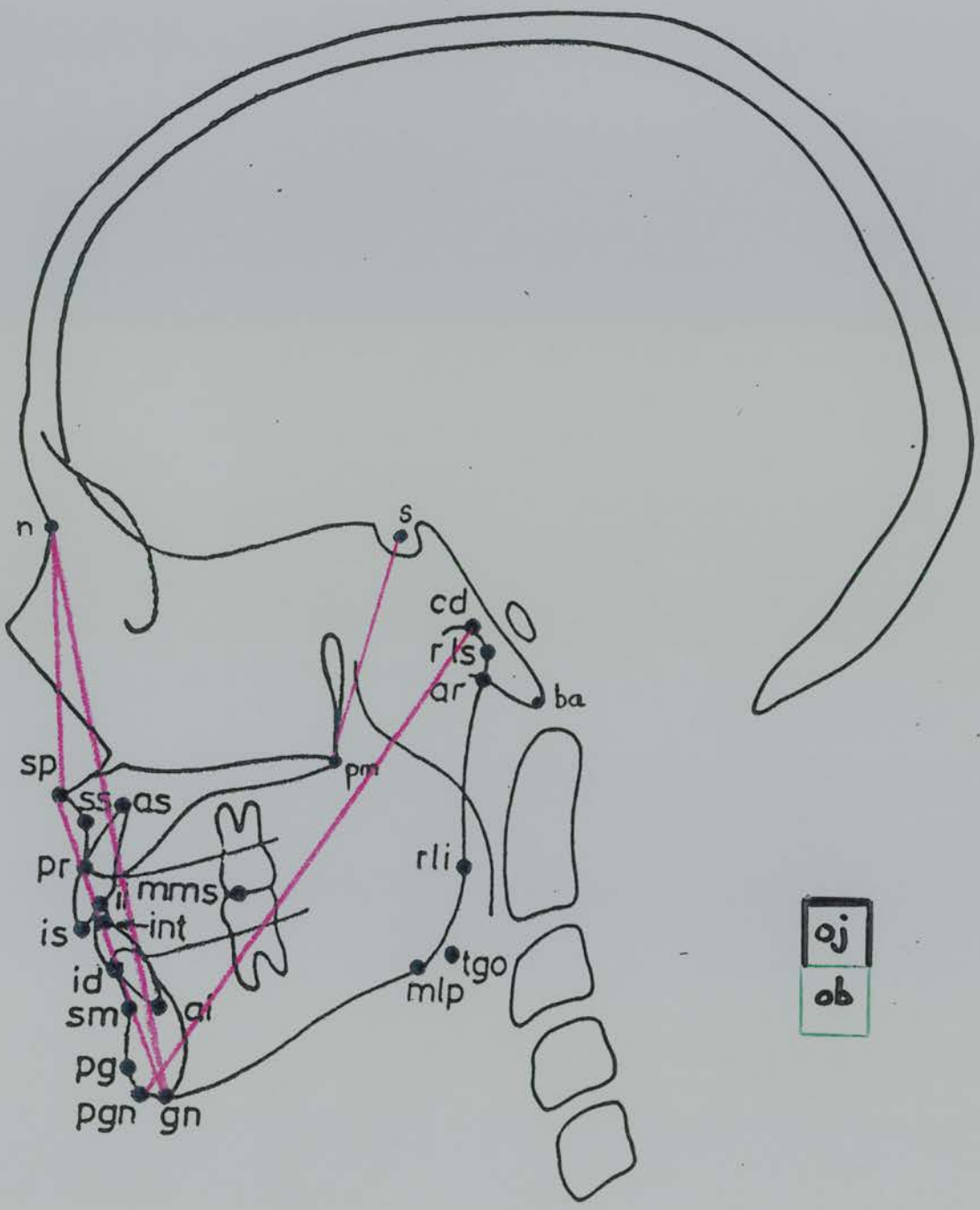
Variable	Anomaly Sample Before Treatment					Anomaly Sample After Treatment							
	Number	Min	Max	Mean	S.D.	Number	Min	Max	Mean	S.D.	Diff.	t	p
pm-ad_3	41	15.3	29.1	22.99	3.39	41	12.9	29.1	23.16	3.37	0.17	-0.50	0.617
tu-ad_3	41	3.7	12.3	6.93	2.09	41	3.6	12.9	7.03	1.74	0.10	-0.41	0.687

E) Craniofacial Morphology - Linear Dimensions

After treatment with RME, all the anterior linear facial measurements increased significantly in both males and females (see Tables 58,59,60). n-sp showed a combined mean difference of 0.88mm ($p<0.001$); sp-gn showed a combined mean difference of 1.88mm ($p<0.001$); and n-gn a combined mean difference of 2.48mm ($p<0.001$). Of particular interest, the variable s-pm between sella and the distal point on the maxilla also showed a significantly larger mean value in the anomaly sample after treatment for both male and female groupings, the combined mean difference being 0.61mm ($p<0.001$). This value has relevance in the movement of the maxilla as a result of treatment, and in the relative sizes of the nasopharyngeal space before and after treatment.

The variables n-s and ss-pm that measure facial depth showed no significant change in the total anomaly sample and in females (see Tables 58,60); the only significant difference was that of n-s ($p<0.05$) in the male group (see Table 59). The overbite reduced significantly in both sexes ($p<0.001$) after treatment, by an overall mean difference of 1.41mm (see Figure 44).

CEPHALOMETRIC LINEAR RESULTS



SIGNIFICANT DIFFERENCES

ANOMALY SAMPLE BEFORE/AFTER TREATMENT

Fig. 44

TABLE 58

CHANGES IN CRANIOFACIAL LINEAR VARIABLES IN MM BETWEEN THE ANOMALY SUBJECTS BEFORE AND AFTER TREATMENT

Variable	Anomaly Sample Before Treatment					Anomaly Sample After Treatment							
	Number	Min	Max	Mean	S.D.	Number	Min	Max	Mean	S.D.	Diff.	t	p
n-s	72	62.0	80.3	72.21	3.724	72	61.7	80.5	72.29	3.826	0.08	-0.72	0.477
n-sp	72	46.7	62.7	54.91	3.870	72	45.9	65.2	55.79	4.095	0.88	-5.00	0.001
n-gn	72	108.0	146.4	124.54	8.287	72	108.3	146.6	127.02	8.076	2.48	-8.89	0.001
s-ba	72	40.3	55.9	47.16	3.510	72	41.2	55.5	47.25	3.447	0.09	-0.79	0.435
s-pm	72	39.9	55.8	48.20	3.546	72	41.5	55.6	48.81	3.333	0.61	-3.90	0.001
sp-gn	72	59.1	87.3	71.04	6.277	72	58.9	89.6	72.92	5.933	1.88	-7.84	0.001
sp-pm	72	47.0	62.7	54.29	3.497	72	46.3	62.3	54.07	3.647	-0.22	1.19	0.239
ss-pm	72	40.5	59.0	49.14	3.868	72	37.5	59.0	48.97	3.542	-0.83	1.10	0.276
pgn-cd	72	107.4	135.6	122.10	7.084	72	108.1	138.0	122.49	6.912	0.39	-2.56	0.013
oj	72	-7.4	12.2	2.51	4.058	72	-5.2	11.5	3.03	3.849	0.52	-1.65	0.104
ob	72	-6.4	3.7	-1.46	2.404	72	-6.6	3.6	-0.05	2.611	1.41	-5.64	0.001

TABLE 59

CHANGES IN CRANIOFACIAL LINEAR VARIABLES IN MM BETWEEN THE MALE ANOMALY SUBJECTS BEFORE AND AFTER TREATMENT

Variable	male sample before treatment					male sample after treatment							
	Number	Min	Max	Mean	S.D.	Number	Min	Max	Mean	S.D.	Diff.	t	p
n-s	31	64.9	80.3	73.63	3.56	31	65.7	80.5	73.92	3.64	0.29	-2.13	0.041
n-sp	31	48.3	62.2	55.54	4.23	31	45.9	65.2	56.61	4.56	1.07	-3.71	0.001
n-gn	31	115.5	146.4	128.24	8.16	31	117.7	146.6	130.80	8.01	2.56	-5.49	0.000
s-ba	31	41.8	55.9	48.85	3.72	31	41.2	55.5	48.95	3.67	0.10	-0.55	0.583
s-pm	31	42.1	55.8	49.85	3.49	31	44.2	55.6	50.35	3.37	0.50	-2.68	0.012
sp-gn	31	67.9	87.3	74.32	4.87	31	67.9	89.6	76.13	4.52	1.81	-5.46	0.001
sp-pm	31	48.8	62.7	55.61	3.54	31	47.4	62.3	55.37	3.98	-0.24	0.75	0.460
ss-pm	31	40.5	59.0	50.07	3.59	31	37.5	59.0	49.86	3.95	-0.21	0.93	0.362
pgn-cd	31	112.9	135.6	124.54	7.42	31	114.1	138.0	124.87	7.19	0.33	-1.00	0.326
oj	31	- 6.2	12.2	2.95	4.24	31	- 5.0	11.5	3.76	3.66	0.81	-1.52	0.140
ob	31	- 6.4	3.7	- 1.79	2.36	31	- 6.6	3.6	-0.22	2.79	-1.57	-3.81	0.001

TABLE 60

CHANGES IN CRANIOFACIAL LINEAR VARIABLES IN MM BETWEEN THE FEMALE ANOMALY SUBJECTS BEFORE AND AFTER TREATMENT

Variable	female sample before treatment					female sample after treatment							
	Number	Min	Max	Mean	S.D.	Number	Min	Max	Mean	S.D.	Diff.	t	p
n-s	41	62.0	78.0	71.14	3.51	41	61.7	78.3	71.05	3.52	-0.09	0.60	0.550
n-sp	41	46.7	62.7	54.44	3.55	41	46.5	63.8	55.17	3.64	0.73	-3.36	0.002
n-gn	41	108.0	136.7	121.74	7.30	41	108.3	137.8	124.16	6.94	2.42	-7.02	0.001
s-ba	41	40.3	50.9	45.87	2.75	41	41.8	50.8	45.97	2.65	0.10	-0.55	0.582
s-pm	41	39.9	54.4	46.96	3.08	41	41.5	54.8	47.64	2.82	0.68	-2.92	0.006
sp-gn	41	59.1	84.4	68.56	6.12	41	58.9	83.1	70.49	5.76	0.93	-5.65	0.001
sp-pm	41	47.0	59.8	53.30	3.15	41	46.3	61.4	53.08	3.06	-0.22	0.91	0.366
ss-pm	41	42.8	55.5	48.44	3.05	41	41.5	55.0	48.31	3.09	-0.13	0.64	0.526
pgn-cd	41	107.4	133.9	120.25	6.30	41	108.1	134.9	120.69	6.19	0.44	-3.90	0.001
oj	41	-3.4	9.7	2.18	3.94	41	-5.2	9.8	2.47	3.95	0.29	-0.78	0.442
ob	41	-5.9	2.5	-1.21	2.44	41	-5.2	3.5	0.08	2.49	1.13	-4.13	0.001

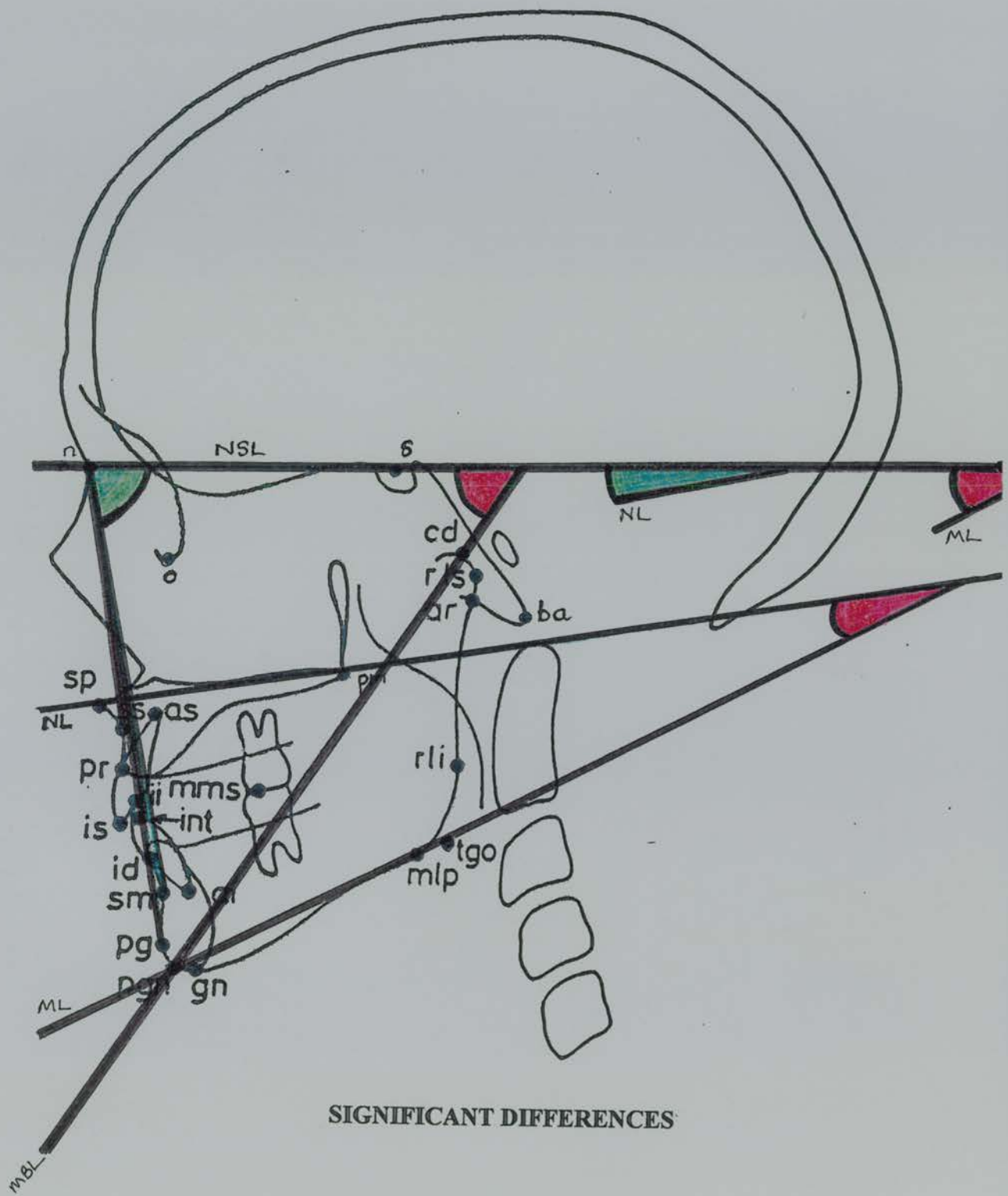
F) Craniofacial Morphology - Angular Dimensions

The analysis of the significant differences within the anomaly sample before and after RME (see Table 61) reveal one surprise - the fact that the angle pm-s-ba showed no statistically significant difference between the two samples; it was expected that, given the increase in dimensions pm-ad_1 and pm-ad_2 after RME, the point pm would have moved forward as a result of the expansion. However, point pm moved only downwards to increase the dimensions of the nasopharyngeal space (see relevance of value s-pm noted previously).

There was some some slight distal tipping downwards of NL; in fact the angle NSL/NL did show a statistically significant reduction between the two means, a small mean difference of 0.5^{o} ($p=0.026$).

The mandibular protrusion relative to the cranial base (s-n-sm and s-n-pg) was significantly reduced ($p<0.001$) with treatment, perhaps due to the auto-rotation of the mandible. The saggital jaw relation angles ss-n-sm and ss-n-pg were found to be significantly greater after treatment ($p<0.001$ and $p=0.016$). T he angle of the mandible to the cranial base NSL/ML increased significantly ($p<0.001$) after treatment, a mean difference of 1.27^{o} - this is consistent with the slight increase in lower facial height previously noted, and with the repositioning of the mandible. Clinically it was probably due to the posterior propping open of the bite as the change from bilateral crossbite to normal bite was achieved. This may also account for the significant difference between NL/ML ($p=0.003$) and NSL/MBL ($p<0.001$) (see Figure 45).

CEPHALOMETRIC ANGULAR RESULTS



SIGNIFICANT DIFFERENCES

ANOMALY SAMPLE BEFORE/AFTER TREATMENT

Fig. 45

TABLE 61

CHANGES IN CRANIOFACIAL ANGULAR VALUES IN DEGREES IN THE ANOMALY SUBJECT WITH TREATMENT

Variable	Anomaly Sample Before Treatment					Anomaly Sample After Treatment							
	Number	Min	Max	Mean	S.D.	Number	Min	Max	Mean	S.D.	Diff.	t	p
n-s-ba	72	116.0	145.3	130.01	5.828	72	114.8	137.5	129.84	5.887	-0.17	0.07	0.937
pm-s-ba	72	44.5	71.1	55.15	5.013	72	44.3	68.3	54.96	4.911	-0.19	0.85	0.396
s-n-sp	72	74.9	94.4	83.79	4.213	72	75.4	94.5	84.06	4.150	0.27	-1.27	0.208
s-n-ss	72	71.1	88.8	78.43	3.940	72	70.0	88.5	78.74	3.890	0.31	-1.96	0.054
s-n-sm	72	67.9	91.4	78.07	4.622	72	67.7	88.8	77.45	4.486	-0.62	3.45	0.000
s-n-pg	72	69.7	92.8	78.88	4.530	72	69.1	89.9	78.16	4.470	-0.72	3.84	0.001
ss-n-sm	72	-6.1	6.3	0.36	3.016	72	-5.7	7.8	1.28	3.267	0.92	-4.88	0.001
ss-n-pg	72	0.1	7.0	2.67	1.857	72	0.1	7.8	3.08	1.810	0.41	-2.47	0.016
NSL/NL	72	-2.6	15.9	8.61	3.863	72	-0.3	14.9	8.10	3.837	-0.51	-2.27	0.026
NSL/ML	72	19.9	49.9	37.59	5.903	72	22.8	52.8	38.86	6.246	1.27	-5.38	0.001
NL/ML	72	18.1	41.1	28.98	5.303	72	16.2	42.1	29.75	5.585	0.77	-3.13	0.003
NSL/MBL	72	49.2	71.6	61.79	4.764	72	51.6	73.7	62.78	5.003	0.99	-4.50	0.001
ML/RL	72	118.9	146.7	130.82	5.512	72	119.3	146.8	131.03	5.615	0.21	-1.29	0.200

6. DISCUSSION

The present study was concerned with the difference between craniofacial, head posture and nasal airway resistance values shown by an anomaly sample of seventy two children aged 10 and 15 years (inclusive), and a control sample of thirty six children of matching age. The anomaly sample subjects all exhibited a full transverse cusp bilateral crossbite. Further, the study then examined and tested the changes that occurred to the anomaly sample subjects when they were treated using rapid maxillary expansion, and considered the inter-relationship between these changes. None of the subjects from either the anomaly or control sample had undergone any surgery to the nasal, tonsilar or adenoidal regions.

The method errors for all the measurement systems were tested and found to be satisfactory both in terms of the equipment used and the ability of the operator to reproduce measurements. The study followed the recommendations of the Committee Report on Standardisation of Rhinomanometry (Clement 1984) and adopted S.I. units, all recordings for nasal airway resistance (N.A.R.) being shown in Pascals/cc/second x 10^3, the resistance value being calculated at a point on the curve corresponding to a pressure difference of 150 Pascals. Rhinomanometry generally is subject to method errors that are larger than those observed in other measurements. Therefore particular care was taken with this aspect of the study, and has resulted in method error values that compare well with previous studies (Solow and Greve 1980, and Sandham 1988). The accuracy whilst measuring N.A.R. was enhanced by using a modified Scuba mask (Hansen et al 1984) and by utilising visual feedback for the patient, a computerised trace on the screen showing the mean of four respiratory cycles (Solow and Greve 1980). The utilisation of an adapted Scuba mask for the pneumotachograph had additional positive points - notably the acceptance by children of a familiar object and

the fact that it only covered the nose, allowing the oral tubing to measure the total nasal resistance to be slightly adapted to obtain optimum readings. However some children found the mask uncomfortable and claustrophobic and were not able to complete readings on all tests. Others found some difficulty in accepting the oral tube for the posterior measurement - this factor was overcome by modifying the tubing with a sleeve, coupled with the Bio-feedback techniques with visual screen presentation.

The NR6 Rhinomanometer was calibrated before each session and proved to be very reliable and robust.

The Rohrer chip in the computer enabled the N.A.R. to be subdivided into values for laminar (k_1) and turbulent (k_2) components and for these values to be compared between the control sample and anomaly sample, and the anomaly sample before and after treatment with RME. This subdivision into laminar (k_1) and turbulent (k_2) values is particularly meaningful when the differing flow patterns of inspiratory and expiratory air are considered. On inspiration, the nasal valve acts as the main resistor in the nasal airway (Proctor 1977; Haight and Cole 1983; Warren et al 1987) causing turbulence in the airflow. This resistance at the nasal valve is regulated by the circumferential alar muscles, and by the erectile tissue on the adjacent septum and turbinates (Hasegawa et al 1979). The airflow then normally passes through the middle meatus, the air being warmed and humidified on passing over the highly vascularised turbinates. When the turbinates are approximate to the nasal septum, as here in the anomaly sample before treatment, there is restriction of airflow, and the nasal blanket stagnates (see Figure 46A). This leads to chemical changes in the composition of the mucopolysaccharides on the nasal mucosa, leading to secondary bacterial rhinosinusitis. The turbulence engendered on inspiration allows the nose to function correctly,

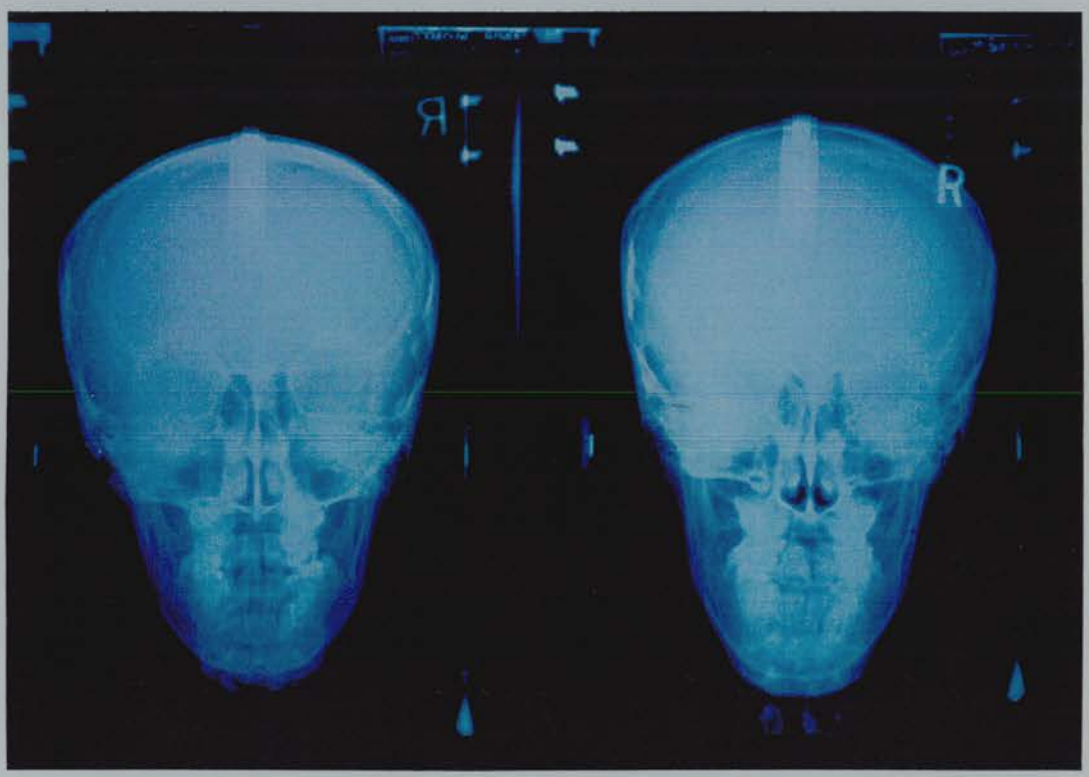


Fig. 46 Effect on intranasal transverse dimensions of treatment with RME

warm, moist filtered air being presented to the delicate alveoli of the lungs, as well as allowing an eddy airflow to pass over the olfactory membrane, and a small flow of air along the floor of the nose (Cole and Haight 1984).

Expired air from the lungs is passed through the nose as a result of a passive deflation of the lungs, and does not require to be warmed, humidified or filtered.

It is important that non-invasive instrumentation is utilised whilst measuring N.A.R, as any invasive technique causes an artificial departure from norm function (Rao and Potdar 1981; Weber et al 1981; Strohl et al 1982; Cole and Haight 1984). In this study, a small diameter pressure recording tube was attached by adhesive tape to the nasal aperture, hence avoiding the necessity of inserting a recording tube into the nares, with consequent distortion of the readings.

Differences between the control sample and the anomaly sample

In the present study, comparison of the N.A.R. of the control sample and anomaly sample before treatment (see Table 21) showed a significantly higher ($p < 0.001$) anterior N.A.R. in the anomaly sample than in the control, a difference of about 200 Pascals/cc/second x 10^3 in both the inspiratory and expiratory modes; the difference in the posterior values was less significant ($p = 0.069$) in the region of 50 Pascals/cc/second x 10^3, as was the laminar flow ($p < 0.005$), these mean values being some 30% higher in the anomaly sample. However, when the values for turbulent flow were appraised, a more significant difference was shown ($p < 0.001$) for both anterior and total values, the mean values of the anomaly sample before treatment being in the region of 50% higher than those in the control sample. There clearly exists, therefore, a significant and demonstrable difference in N.A.R. between the control sample

and the anomaly sample. The readings relating to turbulent flow (k_2) (see Table 22) are in particular significantly higher in the anomaly sample, underlying the importance of accurate measurement of this parameter and the possibility of turbulent flow being a causative factor in the stimulation of mouth breathing as opposed to nasal breathing in a high demand situation.

The airway dimensions pm-ad_1 and pm-ad_2 in the anomaly sample (which had demonstrably higher nasal airway resistance) were found to be significantly smaller ($p<0.001$), a difference of 21.5% and 20.8% respectively, than in the control sample, even though the linear dimension tu-ad_3 was larger. The position of the point pm, the most posterior point on the maxilla, would appear to be relevant, it being in a more distal position in the anomaly sample in relation to other craniofacial structures when compared to the control sample. This is supported by the fact that the angle pm-s-ba is significantly smaller ($p=0.003$) in the anomaly sample than in the controls.

If the transverse variables are considered then a comparison between the control sample and the anomaly sample before treatment shows a number of statistically significant differences at the $p<0.001$ and $p<0.005$ levels. The measurement CNR-CNL, which is the transverse width of the anterior nasal floor, has a mean value of 29.64mm in the control sample and 28.00mm in the anomaly sample, a difference significant at the $p<0.005$ level. The value EMR-EML, the transverse width of the maxillary base, is significantly smaller in the anomaly sample ($p<0.001$) and the measurement between the upper first molars UMR-UML was also significantly smaller ($p<0.001$) in the anomaly sample. Finally, the dimensions NASDIM and MAXDIM both showed significance ($p<0.001$), the anomaly sample being smaller.

Hence the term "adenoidal facies" that was used to describe children with long narrow faces caused, it was thought, primarily by enforced long term mouth breathing, gains support from this study. However, the nasal stenosis causing

the oral breathing pattern here comes not from the adenoidal hypertrophy as described by Linder-Aronson (1970), but by a combination of distal positioning of the point pm (see Table 34) and a significantly narrower width dimension of the nasal bone in the anomaly sample

Motte and Pfister (1960); Linder-Aronson (1970) and Sosa et al (1982) all described typical craniofacial characteristics in "adenoidal facies" children. These included a reduced facial prognathism, a larger anterior facial height and an increased mandibular plane angle. Linder-Aronson attributed many of these differences to a low tongue position, but further research by Solow and Tallgren (1976); Opdebeek et al (1978) and Posnick (1978) suggested that a changed head posture was also involved. Motte and Pfister (1960) and Sosa et al (1982) found craniofacial morphology to be related to radiographic measures of nasopharyngeal airway adequacy. In the present study, with the anomaly subjects exhibiting high nasal resistance coupled with reduced nasopharyngeal and lateral nasal and maxillary dimensions, it was found that the anterior facial height is significantly larger than in the controls, the upper face height n-sp at the $p=0.018$ level and the lower face height sp-gn at the $p=0.019$ level. Other significant differences between the two samples relate to small facial depth, n-s ($p=0.021$), longer clivus length s-ba ($p=0.019$), shorter maxillary length ss-pm ($p=0.005$) found in the anomaly sample as well as the significantly larger ($p<0.001$) variable pgn-cd in the anomaly sample (see Table 40). All these findings support previous research (Wertz 1970; Bushey 1977; Jonas et al 1982; Solow et al 1984). The mandibular angle NSL/MBL was highly significantly larger in the anomaly sample, as was the angle ML/RL ($p<0.001$). These angular values, coupled with the significantly larger linear dimension pgn-cd, suggest that the growth pattern in the anomaly sample has been predominantly downwards, contributing to the long faced

sample compared to the control sample reflect the downward and forward growth of the mandible found in long faced children.

It has been noted in many previous studies of subjects with upper airway problems that the craniofacial morphological differences compared to control subjects included a reduced facial prognathism and a larger mandibular plane angle in relation to the anterior cranial base.

In the present study, the angle pm-s-ba, one of the measurements of nasopharyngeal patency, has a considerably smaller value in the anomaly sample before treatment, having a mean value 3.47° less than in the control sample. However the angle n-s-ba was practically identical in the two samples. Therefore this shows that as the point pm was retruded in the anomaly sample, and the maxillary length sp-pm was identical in the two samples, then the maxillary complex must be retruded in the anomaly sample compared to the control.

The mandibular plane angle NSL/ML also showed a highly significant and larger value in the anomaly sample, as indeed did the angle ML/RL.

Hence the results of the present study support the previous findings, with the maxillary complex in the anomaly sample significantly retruded, both in relation to the anterior cranial base and to the mandible. The anomaly sample also had a larger mandibular plane angulation.

In 1977, Solow and Tallgren showed that extension of the head in relation to the cervical column was associated with a number of craniomorphological factors, findings supported by Opdebeek et al (1978) and Marcotte (1981). In 1970, Linder-Aronson demonstrated that patients with upper airway obstruction due to enlarged adenoids had a significantly different craniofacial morphology from a control group, and in 1979 Solow and Greve demonstrated the association between

craniocervical angulation and respiratory resistance in a group of children before and after adenoidectomy. Their findings showed that a large craniocervical angulation was seen in conjunction with an increased nasal airway resistance in the subjects before adenoidectomy as compared with a control group. Solow et al (1984) reported a significant correlation between the obstructed nasal airway (defined as a small pm-ad_2 value and a high NAR), and a large craniocervical angle. The values NSL/CVT and NSL/OPT were used to determine craniocervical angulation.

In the present study, the anomaly sample showed a significant increase in nasal airway resistance but, unlike those with adenoidal problems in previous studies, did not show statistically significant differences in craniocervical angulation when compared to a control group. The reason for this is possibly that in the group that had adenoid problems, the stenosis was in relation to the nasopharynx, hence extension of the head in relation to the cervical column would tend to open the nasopharyngeal airway, making breathing through the nose easier. However in the anomaly group investigated in the present study, the fact that they had bilateral crossbites tended to locate the stenosis anteriorly in the nasal cavity, hence extension of the head in relation to the cervical column would not make any appreciable difference to the passage of air.

The relationship between head posture, craniocervical angulation and craniofacial morphology was the subject of a hypothesis suggested by Solow and Kreiborg (1977). It was suggested that subjects exhibiting increased nasal airway resistance extended the head in relation to the cervical column in order to maintain their vital airway adequacy. This head extension led in turn to stretching of the facial soft tissues, resulting in differential forces on the facial skeleton with consequent effect on craniofacial growth. The net result was the "adenoidal facies".

An analysis of the associations between specific variables relating to anterior facial height and head posture reveals a comprehensive pattern of associations in the anomaly sample (see Table 48). The head posture variables NSL/CVT and NSL/OPT showed positive associations with upper facial height n-sp, lower facial height sp-gn and NL/ML, the angular measurement of lower facial height. Hence a large anterior facial height was seen with a large craniofacial angulation.

Negative associations were seen in the anomaly sample and in the control sample between the head posture variables and the measurements of airway adequacy pm-ad_1 and pm-ad_2. Hence the larger the head posture variables, the smaller the airway dimension value.

It would appear therefore that the present study goes a considerable way to supporting the Solow and Kreiborg (1977) control system hypothesis.

Changes with treatment

Examination of the values of the variables examined after the anomaly sample had undergone treatment with Rapid Maxillary Expansion reveals much to discuss.

Hershey et al (1976), Turbyfill (1976) and White and Woodside (1989) all reported that nasal airway resistance decreased after an anomaly sample was treated with rapid maxillary expansion. They all found the resistance to have decreased by 40-45%. The present study supports their findings, the anterior inspiratory nasal resistance value decreasing by about 176 pascals/cc/second x 10^3, the expiratory by 145 pascals/cc/second x 10^3, both significant at the $p<0.001$ level. The total nasal airway resistance also significantly decreased ($p<0.001$) by 73 pascals/cc/second x 10^3 for inspiration and 84 pascals/cc/second x 10^3 for expiration.

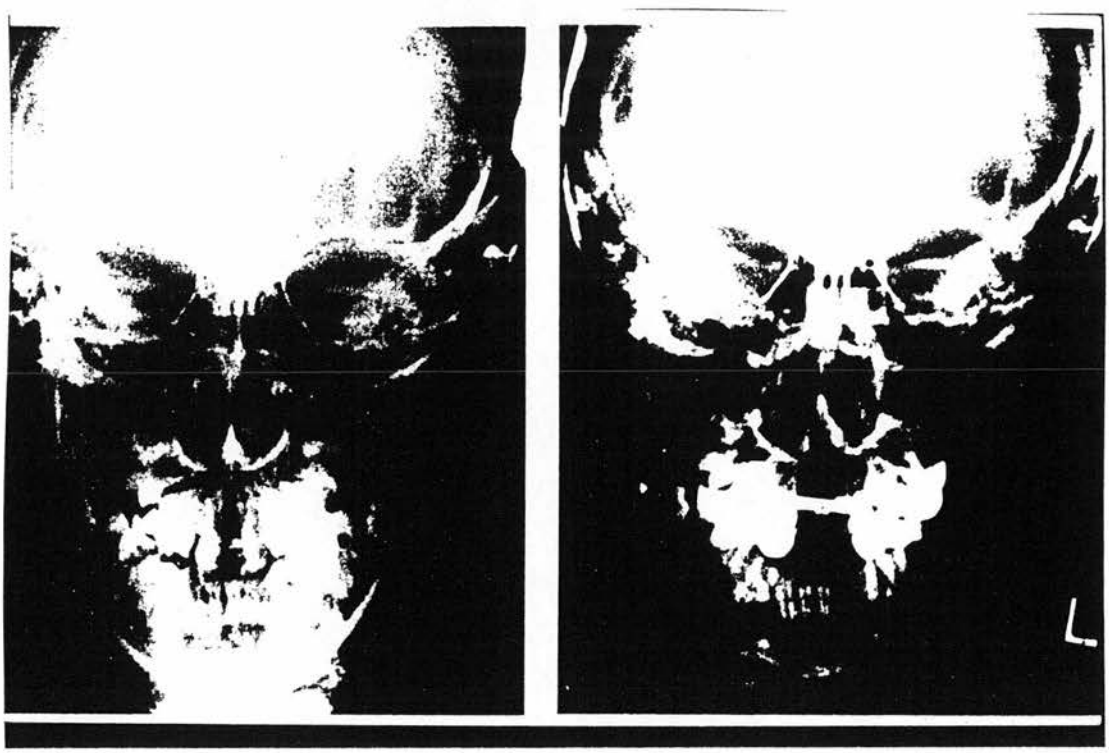
The laminar (k_1) and turbulent (k_2) components also showed a highly significant decreased after RME. These variables have not been studied before in relation to RME, and an interesting pattern has emerged. Warren in 1979 pointed out that

airflow resistance varies inversely as to the fourth power of the radius of the tube through which it passes, so a small increase in the dimension of the tube makes considerable difference to the nasal airway resistance measurement. Certainly it would appear that, within the nose, the area of maximum nasal resistance is anteriorly in the region of the nasal valve and inferior turbinates (Proctor et al 1977; Haight and Cole 1983). Anatomically and radiographically it can be seen (see Figure 46) that the main increase in the width of the nasal cavity following RME is particularly on the anterior nasal floor region (Haas 1961; Wertz 1970' Gray 1975' Montgomery et al 1979; Pavlin et al 1984), so one would expect that there would be a significantly decreased nasal resistance value if, as here in the anomaly sample, the stenosis is primarily anteriorly in the nose. Clinically this is shown by noted ability of the patients to breathe with greater ease through the nose, probably due to the inferior turbinate bones moving away from the nasal septum (see Figure 46B), together with some expansion of the alar valve, leading to less turbulence in the air passing over the inferior turbinates. The observed reduction or complete cessation of snoring, with more restful and productive sleep, is also extremely important.

The Null hypothesis relating to nasal airway resistance are that:

1. There will be no difference in the mean value of laminar and turbulent airflow between the control and anomaly sample

2. There will be no change in the mean value of laminar and turbulent airflow after treatment with Rapid Maxillary Expansion



A B

Fig. 47 Transverse changes in the maxillary dimensions as a result of treatment with R.M.E.

Of the 36 mean values relating to nasal airway resistance in the present study, 33 showed significant differences, hence it was possible to reject the Null hypotheses for these values. For the remaining 3 values, although they did not reach statistical significance, a definite trend was established.

Overall, therefore, the Null hypotheses relating to differences in nasal airway resistance between the control sample and the anomaly sample, and changes in nasal airway resistance due to treatment can be rejected, in that the results showed that the Nasal Airway Resistance was significantly higher in the anomaly sample, but was significantly reduced by treatment with RME.

The nasal respiratory results of this study support previous research into the interrelationship between RME and NAR, the effects of the reduction in the turbulent component of nasal airflow being of particular interest.

From a clinical point of view, there is an observed change from predominantly oral respiration to nasal respiration after RME.

Utilisation of a cast maxillary expansion splint (see Figure 47) (Grossman 1963) as opposed to a band-borne appliance is of paramount importance in ensuring the rigidity of the expansion, so minimising buccal tooth tip and transferring as much as possible of the expansion force to the midpalatal suture and so to the nasal complex. When the maxillary suture splits it does so in a fan-like manner, wider at the front than at the back of the palate (Timms 1980), and wider at the oral junction of the suture rather than at the nasal site (Haas 1961, 1970). The present study showed significant transverse intranasal width increase after RME, the total width of the anterior nasal base (CNR-CNL) increasing by 10.5%. The changes noted in each half of the nasal transverse dimension, CNR-CNM, and CNM-CNL were approximately the same. This lateral dimensional increase in the anterior part of the nose assumes considerable relevance when coupled with the reduction in nasal airway resistance previously

noted. The relationship between the maxillary suture expansion and upper molar expansion was previously studied by Krebs (1964) using implants. He discovered that the average sutural opening was about one half of the dental arch expansion. Analysis of the mean differences in the present study support this assertion, the intermolar width UMR-UML increasing by a mean of 7.77mm, whilst the maxillary suture width increased by 2.96mm. In addition, the maxillary base EMR-EML only expanded by a mean of 2.15mm, underlying the importance of building in maximum rigidity to appliance design, as even with the cast appliance used in this study there would appear to be have been two components to the expansion, one of the palatal shelf and one of molar buccal tipping. It is the latter that is particularly prone to relapse (Linder-Aronson and Lindgren 1979), and it is possibly true that inadequate band-borne appliances have contributed to the poor relapse record of rapid maxillary expansion. One of the most obvious signs accompanying the opening of the midpalatal suture is the diastema that forms between the upper central incisors. This separation, however, cannot be reliably used as an indicator of suture opening (Haas 1961), and tends to close spontaneously due to the pull of the transeptal fibres, eventually leading to tooth extrusion and arch length shortening (Wertz 1964). This diastema formation was found to be highly significant at the $p<0.001$ level, the subsequent relapse being prevented by using sectional fixed appliances to the upper incisors, the wire being attached to tubes soldered to the rapid maxillary cast appliance.

The effects of RME on the mandibular arch width dimension were described as unpredictable by Gryson (1977) who recorded no significant width changes. However Haas (1965 and 1970) and Sandstrom et al (1988) noted a significant change after treatment. The present study showed a significant

increase ($p=0.002$) in the mandibular intermolar width after RME, perhaps due to the uprighting of the lower molars as a secondary effect of intercuspal activity with the upper molars.

The Null hypotheses to be tested in relation to the transverse craniofacial dimensions were:

1) That there would be no difference in the transverse craniofacial dimensions between the control sample and the anomaly sample
2) That there would be no change in the transverse craniofacial dimensions of the anomaly sample after treatment with RME.

In turn:

1) Control/Anomaly - significant differences were found between seven of the eleven variables examined. Of the remaining four, three - MIR-MIL, MIR-C_2, C_2-MIL - related only to the mesial surfaces of the upper central incisors, so they can be discounted. The fourth variable, that of mandibular intramolar width, did show the anomaly sample mean value to be less than the control, but not significantly so.

The Null hypothesis can therefore be rejected.

2) Anomaly sample with treatment - of the eleven variables measured, the mean differences were significant in ten.

The Null hypothesis can here also be rejected.

It can be seen that the effect of RME on the anterior nasal cavity is significant. What then of the changes observed in posterior nasal dimension. The positioning of the maxilla after RME was investigated by Haas (1961) and Wertz (1970). They found that the final position of the maxilla after treatment was somewhat unpredictable, but that there was routinely a downward and forward displacement of the maxilla. Timms (1979) came to a similar

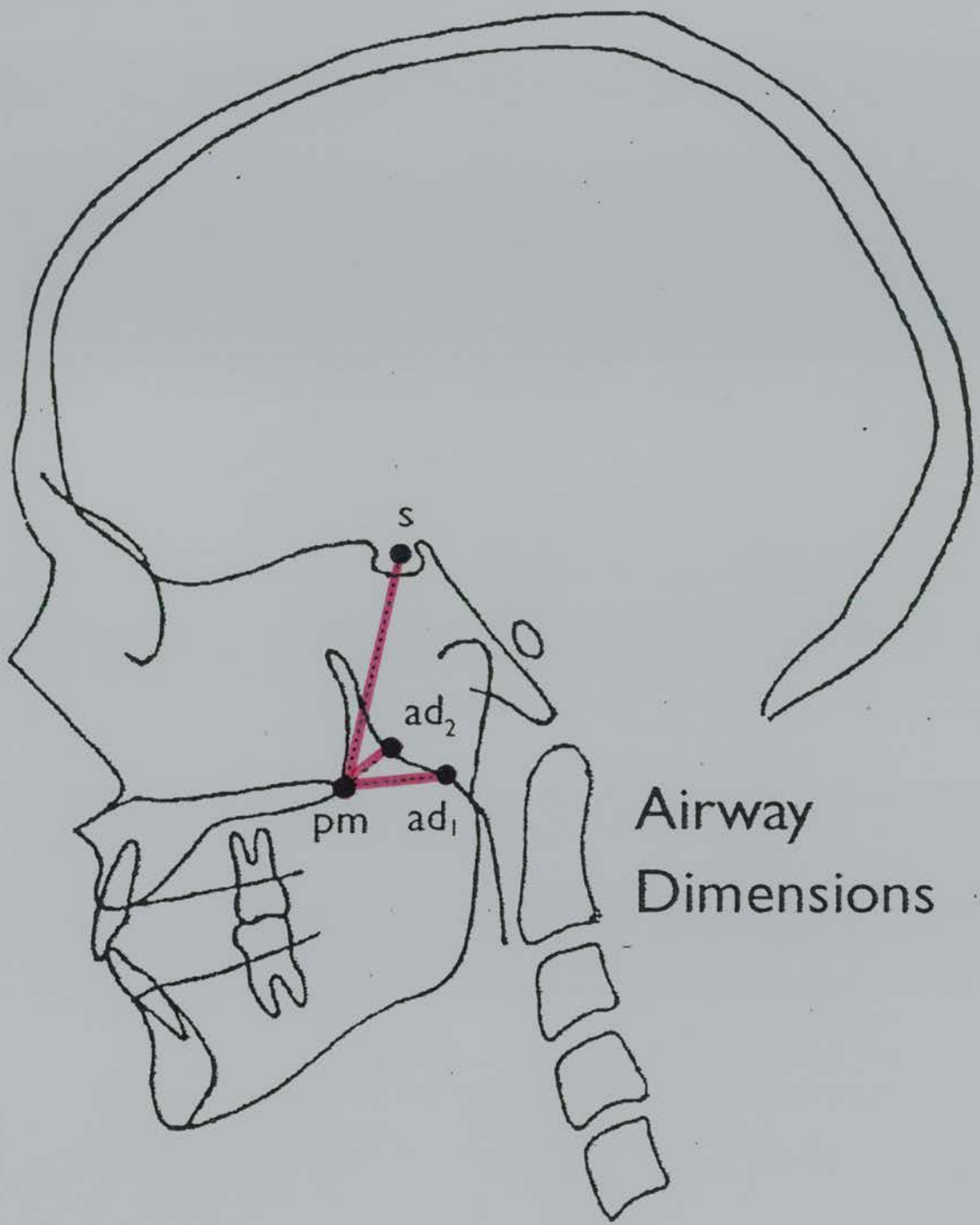


Fig. 48 Significant changes in posterior airway dimensions as a result of treatment with R.M.E.

conclusion, pointing out that the rotation of the maxillary shelves relative to the palatine bone propped the maxilla forwards during expansion. In the present study, examination of the changes in the variables pm-ad_1 and pm-ad_2 due to RME showed that significant ($p<0.001$) increases in dimension occurred, appearing to support the contention that the maxilla moves forward, hence increasing the size of the available air passageway, and contributing to the decrease in N.A.R. seen after RME. In addition, the linear value s-pm also significantly increased, the maxilla moving apparently downwards as well as forwards (see Figure 48), supporting the findings of previous research. However, there was no change in pm-s-ba so it would appear that the observed airway dimensional changes are largely a result of downward movement of the point pm on the posterior end of the maxilla, rather than forward.

The Null hypotheses relating to airway dimensions were:

1) That there will be no difference in the following airway dimensions pm-ad_1, pm-ad_2, pm-ad_3 and tu-ad_3 between the control and anomaly samples
2) That there will be no change in the values of pm-ad_1, pm-ad_2, pm-ad_3 and tu-ad_3 as a result of treatment of the anomaly sample with RME.

In turn:

1) Control/Anomaly - The Null hypothesis can be rejected for the three variables pm-ad_1, pm-ad_2 and tu-ad_3. However, when pm-ad_3 is examined, the Null hypothesis can be rejected in the male sample only.

2) Anomaly with treatment - The Null hypothesis can be rejected with regard to the variables pm-ad_1 and pm-ad_2. However, these are the two variables that are regarded as the standard measures of posterior nasal airway patency.

Given the short duration (mean 3.75 weeks) of the treatment, it should not be expected that linear and angular variables remote from the maxillary/nasal treatment site would change significantly.

After treatment with RME, however, it was found that the anterior facial height (n-gn) increased significantly, especially the lower facial height component sp-gn. This latter dimensional increase presumably reflects the dental change from a bilateral buccal crossbite to amore normal occlusion without buccal crossbites, which occurs as a result of the treatment, hence leading to a propping open of the bite, and the observed increase in the angles NLS/ML, NL/ML and NLS/MBL. The overbite in consequence reduced significantly. The bite opening effect however has been reduced in the present study by using cast capping splints rather than banded palatal expanders, the latter tending to extrude the teeth on expansion (Sarver and Johnston 1989). Bishara et al (1987) found the bite opening that occurs on expansion to be of a temporary nature. Majouran and Nanda (1994) found the use of a chin cap during treatment to be useful.

The linear variables s-pm also showed a significant increase after treatment, this movement having the effect of increasing the dimensions of the nasopharyngeal space pm-ad_1 and pm-ad_2, hence allowing easier passage of air through the nasopharynx.

The Null hypothesis relating to linear craniofacial dimensions were:

1. That there will be no difference in the following linear craniofacial morphology values between the control and anomaly sample

n-s	sp-pm
n-sp	ss-pm
n-gn	pgn-cd
s-ba	oj
s-pm	ob
sp-gn	

2) That there will be no change in these values before and after treatment of the anomaly sample with Rapid Maxillary Expansion.

1) Control/Anomaly Sample

Significant statistical differences in both males and females were found in three of the eleven variables tested, pgn-cd, oj and ob. The null hypothesis can be rejected for these variables in both males and females.

In addition, in the males, a further four variables, n-sp, n-gn, s-ba and sp-gn showed significant statistical differences, so the null hypothesis can be rejected for these variables in relation to male subjects only.

In the females two further, different, variables n-s and ss-pm showed significant statistical differences. The hypothesis can therefore be rejected for these variables for female subjects.

2) Anomaly sample before and after treatment

Significant statistical differences in both males and females were found in five of the eleven variables tested: n-sp, n-gn, s-pm, sp-gn and ob.

The Null hypothesis can therefore be rejected for these variables in both males and females.

With the exception of the mildly significant difference in n-s ($p<0.05$) for males only, the other values showed no significant change. However, as the variables n-s, s-ba, sp-pm and ss-pm are measurements of bone length, one would not expect them to change as a result of a short course of RME.

Taking these constraints into consideration, the hypothesis can be rejected in total.

The Null hypotheses relating to angular craniofacial morphology values were:

1) There will be no difference between the control sample and anomaly sample for the angles

n-s-ba	ss-n-sm
pm-s-ba	ss-n-pg
s-n-sp	NSL/NL
s-n-ss	NSL/ML
s-n-sm	NL/ML
s-n-pg	NSL/MBL
	ML/RL

2) There will be no change in the above angles before and after treatment with Rapid Maxillary Expansion.

1) Control sample and anomaly sample

Of the thirteen variables tested, nine showed significantly different values between the control and anomaly sample. It was thus possible to refute the Null hypothesis relating to these variables.

The variable NSL/NL showed a positive trend, although not statistically significant, and the variables n-s-ba, s-n-sm and s-n-pg were virtually the same in both samples.

2) Anomaly sample before and after treatment

Of the thirteen variables tested, nine showed significant differences, and the Null hypothesis can be refuted for these variables.

The other four variables, n-s-ba, pm-s-ba, s-n-sp and ML/RL, remained virtually unchanged before and after treatment with RME.

Solow and Greive (1979) found that the nasal airway resistance and craniocervical angulation was reduced significantly after adenoidectomy, there being a reduction of some 2^{o} in head posture angulation measured two months after the operation, and a reduction of some 30% in nasal resistance. Similar results were also gained by Woodside and Linder-Aronson (1979).

The present study showed no significant changes in head posture as a result of RME, with the exception of the variable OPT/HOR, despite a highly significant drop in nasal airway resistance. The differences in findings between the effects of adenoidectomy and those of RME on head posture may be explained by the fact that in the adenoidectomy anomaly sample the airway stenosis is predominantly in the nasopharynx; in the anomaly sample treated with RME, the problem lies mainly within the anterior part of the nose. In addition, in the present study the short time scale between the recordings (mean 3.75 weeks) may not have allowed sufficient time for long established head posture habits to be corrected.

The Null hypotheses relating to head posture were:

1) That there will be no difference in the craniocervical angles NSL/OPT and NSL/VER between the control and anomaly sample;
2) That there will be no change in the craniocervical angles NSL/OPT and NSL/VER in the anomaly sample before and after treatment with RME.

1) Statistically, it was not possible to refute the Null Hypothesis, but there was a distinct and measurable tendency for there to be a larger craniocervical angle in the anomaly sample before treatment as compared to the controls.
2) There was no significant change here, except for OPT/HOR ($p=0.032$), so it is not possible to refute the Null hypothesis.

Summary

The present study has aimed to develop further understanding of the craniofacial form, nasal airway resistance and head posture firstly in an anomaly sample exhibiting bilateral crossbite, comparing it to a control sample; and secondly to examine the changes that occur in the above parameters when the anomalous subjects are treated with Rapid Palatal Expansion. The control sample was considered representative of the craniofacial form of children in the catchment area and the anomaly sample compared well with those assembled for previous studies. The control sample of 36 children was considered large enough, but problems of acceptance occurred during the measurement of nasal airway resistance, particularly in the posterior part, which reduced the sample size somewhat, especially when sub-divided into males and females for comparison purposes. It is hoped that further developments in rhinomanometrical measurement will obviate this difficulty.

The treatment undertaken on the anomaly subjects followed current best practice and the records that were taken radiographically, photographically and as plaster casts, did not exceed the norm. The short time period between before and after treatment records fulfilled the needs of the study but consideration should be given to a longer term follow-up to investigate the possibility of significant differences occurring over an increased time span in head posture variable changes, and to identify any relapse characteristics. This will be the subject of future work, as will the effect of RME on the soft tissue profile and an investigation into whether the age of the patient within the 10-15 years old window has any bearing on the efficacy of rapid maxillary expansion. However, the combination of a wide array of methodology has allowed certain conclusions to be reached, and has given a new perspective to the complex inter-relationships examined.

7. CONCLUSIONS

A) When the control and anomaly samples are compared:

(i) The N.A.R. of the anomaly sample is significantly higher, particularly the turbulent (k_2) component.

(ii) The airway dimensions pm-ad_1 and pm-ad_2 are significantly narrower in the anomaly sample - mainly due to the position of point pm.

(iii) The width of the nasal floor CNR-CNL, the maxillary base EMR-EML and the upper molar width UMR-UML are significantly narrower in the anomaly sample.

(iv) The anomaly sample exhibits significantly larger anterior facial height n-gn, especially lower facial height sp-gn, as well as a significantly longer variable cd-pgn. The whole face is thus measurably longer than in the control sample.

(v) The facial depth of the anomaly sample, measured by n-s and ss-pm, is significantly less, and pm-s-ba angle was significantly less, hence the midface is retruded.

The conclusion for this element of the study is that children who exhibit a bilateral dental crossbite with no adenoidal hypertrophy, but with a high nasal airway resistance, show significantly measurable differences in craniofacial morphology, and a tendency to an increased craniocervical angulation when compared to a control group.

B) When the anomaly sample before and after treatment with RME is examined:

(i) The N.A.R. of the anomaly sample after treatment is significantly reduced.

(ii) The airway dimensions pm-ad_1 and pm-ad_2, and the posterior maxillary height s-pm, are significantly increased, due primarily to a downward displacement of the point pm. The posterior airway is thus considerably more patent.

(iii) The width of the nasal floor CNR-CNL, the maxillary base EMR-EML and that of the intermolar distance UMR-UML, are all significantly increased after RME. Hence the inferior turbinate stricture is alleviated, and the dentition attains normal intercuspal relationships.

(iv) Despite the short time interval (3.75 weeks mean) some craniofacial variables show significant changes - the anterior facial height increases as a result of changing lateral intercuspation - this trend has been minimised by using cast splints, and should be a temporary one in the longer term.

(v) The head posture variables NSL/CVT and NSL/OPT show no significant changes after RME.

Intraorally the appearance and the function of the dentition is dramatically improved.

The conclusions reached in this section of the study are that RME certainly benefits the child in as far as the reduction in nasal airway resistance leads to the alleviation of related apnoeic problems and an improved nasal function, without resort to any surgical intervention intra-orally or intranasally. The main craniofacial changes occur in the increased width of the nasal floor and the maxillary base, together with a downward movement of the posterior part of the maxilla with treatment.

Long term benefits relating to the interception of long face syndrome require further investigation.

8 GLOSSARY OF EQUIPMENT USED

a) Radiography

Cephalometric Radiography Machine

Panelipse with cephalometric attachment

Head Type 100 EC

Anode 3703

Tube E 75 21 N

Date of manufacture 1979

Serial Number 1465

J Morita Corporation
11-13, 2-Chome Ueno
Taito-ku
Tokyo 110, Japan

Parallel Grid

No. 68 02 830 G100E

Serial Number N70 136

Ratio 6:1

Size 24cm x 30cm

70 Absorbing Strips per cm.

Elema-Schonander
Solna, Sweden

Cassette

Trimax T16 cassette

24cm x 30cm

Rare earth screens

3M Company plc
Scotland

Radiographic Film

Trimax XD

24cm x 30cm

3M Company plc
Scotland

b) **Rhinomanometry**

Rhinomanometric Machine

NR6 configuration - nasal resistance meter

Zero system - push button

Resistance to Air Flow - approx. 5mm H_2O at 500cm^3/sec

Pressure Range - $\pm$ 1000 Pa

Flow Range - $\pm$ 1000 cm^3/sec

Accuracy - $\pm$ 2%

Mercury Electronics
Pollock Castle Estate
Newton Mearns, Glasgow

Computer

British Broadcasting Corporation Microcomputer System

(BBC Model Master B 128)

Acorn Computers
Cambridge

Printer

Epson FX80

Epson UK plc
Dorland House
388 High Road
Wembley, Middlesex

Monitor

Apple Monitor Model AZMZO 1OP

Green Phosphor Screen

Serial Number 9952645

Apple Computer
20525 Mariani Avenue
Cupertino
California 95014, USA

Calibration Unit

Dynamic calibration machine

Producing pressure peak at 500 Pascals

Flow peak at 150 litres/sec^3

Mercury Electronics
Pollock Castle Estate
Newton Mearns, Glasgow

Nasal Catheter Adhesive Tape

Lenkoflex Tape

Beiersdorf A.G.
Hamburg, Germany

Oral Catheter Tips

4mm Otoscope disposable tips

Keeler Medical Manufacturing
London

Nasal Spray

Otrivine Decongestant

Xylometazoline hydrochloride B.P.

0.1%

Ciba Laboratories
Horsham, West Sussex

c) Digitiser

GTCO Corporation
Digipad 5
Rockville, USA

d) Printer

IBM "Proprinter"

IBM
Livingston, Scotland

APPENDIX

NAME _____ DOB _____ HOSPITAL NO. _____

NO. 1

AGE 2

SEX MALE - 1 FEMALE - 2 3

ANGLES
CLASS I - 1
CLASS II - 2
CLASS II - 3 4

NASAL INSUFFICIENCY
BEFORE TREATMENT
YES - 1
NO - 2 5
AFTER TREATMENT
YES - 1
NO - 2
IMPROVED - 3 6

NOSE/MOUTH BREATHER
BEFORE TREATMENT
NOSE - 1
MOUTH - 2
MIX - 3 7
AFTER TREATMENT
NOSE - 1
MOUTH - 2
MIX - 3 8

SNORER
BEFORE TREATMENT 8a
AFTER TREATMENT 8b

PREVIOUS ORTHO.
YES - 1
NO - 2 9

PREVIOUS SURGERY
NONE - 1
ADENOIDS - 2
TONSILS - 3
NOSE - 4
OTHER - 5 10

PARENTAL PROBLEM (NT)
YES - 1
NO - 2 11

SIBLING PROBLEM (NT)
YES - 1
NO - 2 12

DATE INITIAL TEST 13

TESTS YES - 1
NO - 2
X-RAY 14
S/M 15
RHINO 16
PHOTOS 17

DATE BEGIN ACTIVATION 18

DATE END ACTIVATION 19

DATE SECOND TEST 20

TESTS YES - 1
NO - 2
X-RAY 21
S/M 22
RHINO 23
PHOTOS 24

DATE THIRD TEST 25

TESTS YES - 1
NO - 2
X-RAY 26
S/M 27
RHINO 28
PHOTOS 29

DISPOSAL
EDH - 1
FIFE - 2
OTHERS - 3 30

Dean of Dental Studies:
PROFESSOR P. SUTCLIFFE
Secretary to the School of Dental Surgery:

SCHOOL OF DENTAL SURGERY,
OLD HIGH SCHOOL,
12 INFIRMARY STREET,
EDINBURGH EH1 1LT

Tel. 031 667 1011

23 September 1988

Mr. James P. McDonald,
Edinburgh Dental Hospital
Orthodontic Department,
Chambers Street,
Edinburgh, EH1 1JA

Dear Jim,

LOTHIAN AREA DENTAL ETHICAL COMMITTEE

Your request for ethical approval to study 'The Effect of Rapid Maxillary Expansion on Craniofacial Form, Nasal Airway Patency, and Head Posture' has been approved by two members of the Area Dental Ethical Committee. Our normal procedure is that straightforward applications such as the present one are approved by two members of the Committee and their decision is homologated when the whole Committee meets annually. You may therefore proceed with this study when you are ready.

Yours sincerely,

John.

Professor J.C. Southam,
Chairman, L.A.D.E.C.

JCS/mrm

REFERENCES

Adams C P (1963) "An investigation into the relation between face width and upper dental arch width in five year old children." European Orthod Soc 126, 265-280.

Alpern M C, Yurosko J J (1987) "Rapid expansion in adults with and without surgery." Angle Orthod 57, 245-263.

Alvi A R (1985) "Evaluation of rare earth intensifying screens for cephalometric radiography." Amer J Orthod. 88, 268.

Angell E H (1860) "Treatment of irregularity of the permanent or adult teeth." Dental Cosmos 1, 540-544.

Angle E H (1907) "Treatment of Malocclusion of the Teeth." S S White, Philadelphia 7th Ed.

Aschan G, Drettner B, Ronge H E (1958) "A new technique for measuring nasal resistance to breathing, illustrated by the effects of histamine and physical effort." Ann Acad Regiae Sci Upps 2, 111-126.

Baldini G, Luder H (1982) "Influence of arch shape on the transverse effects of transpalatal arches of the Goshgarian type during the application of buccal root torque." Amer J Orthod 81, 202-208.

Barber A E, Sims M R (1981) "Rapid maxillary expansion and external root resorption in man: A scanning electron microscope study." Amer J Orthod 79, 63-65.

Baum A T (1951) "A cephalometric evaluation of the normal skeletal and dental pattern of children with excellent occlusions." Angle Orthod 21, 96-103.

Baumrinds S (1987) "Quantitation of maxillary remodelling - a description of osseous changes relative to superimposition on metallic implants." Amer J Orthod. 91, 29-41.

Beer G R (1947) "How animals hold their heads." Proc Linnean Soc 158, 125-139.

Behlfelt R, Linder-Aaronson S, Neander P (1990) "Posture of the head, the hyoid bone and the tongue in children with and without enlarged tonsils." Eur J Orthod 12, 458-467.

Bell R, Lecompte E J (1981) "The effects of maxillary expansion using a quadhelix appliance during deciduous and mixed dentitions." Amer J Orthod 79, 152-161.

Bell W H, Epker B N (1976) "Surgical orthodontic expansion of the maxilla." Amer J Orthod 70, 517-528.

Bell W, Jacobs J (1979) "Surgical-orthodontic correction of horizontal maxillary deficiency." J Oral Surg, 37, 897-902.

Bench R W (1963) "Growth of the cervical vertebrae as related to tongue, face and denture behavior." Amer J Orthod 49, 183-214.

Bende M (1984) "Contralateral effects of unilateral nasal decongestion." Acta Otolaryngol (Stockh) 99, 637-640.

Bergland O (1963) "The Bony Nasopharynx." Acta Odont Scand 21: Suppl 35 pp 18,42,125.

Bergland O, Semb G (1986) "Elimination of the residual alveolar cleft by secondary bone grafting and subsequent orthodontic treatment." Cleft Palate J 23, 175-205.

Bishara S E (1981) "Longitudinal cephalometric standards from 5 years of age to adulthood. Amer J Orthod 79, 35-44.

Bishara S E, Peterson L C (1983). "Longitudinal changes in the ANB angle and Wits appraisal: Clinical implications." Amer J Orthod 84, 133-139.

Bishara S, Staley R N (1987) "Maxillary expansion - clinical implications." Amer J Orthod 91, 3-14.

Bjerin R (1957) "A comparison between the Frankfort Horizontal and the Sella Turcica-Nasion as reference planes in cephalometric analysis." Acta Odont. Scand. 15: 1-12.

Björk A (1951) "Some biological aspects of prognathism and occlusion of the teeth." Angle Orthod 21, 3-27.

Björk A (1953a) "Estimation of age changes in overjet and sagittal jaw relation." Trans Europ Orthod Soc 126, 240-256.

Björk A (1953b) "Variability and age changes in overjet and overbite." Int Dent J 4, 718-744.

Björk A (1955) "Cranial Base Development. A follow-up x-ray study of the individual variation in growth occurring between the ages of 12 and 20 years and its relation to brain case and face development." Amer J Orthod 41, 198-225.

Björk A (1960) "The relationship of the jaws to the cranium." Chapter 7 in Lundstrom A (ed) "Introduction to Orthodontics." New York, McGraw Hill pp 104-140.

Björk A (1963) "Variations in the growth pattern of the human mandible: Longitudinal radiographic study by the implant method." J Dent Res 42, 400-411.

Björk A (1964) "Sutural growth of the upper face studied by the implant method." Trans Europ Orthod Soc 126, 49-65.

Björk A, Skieller V (1974) "Growth in width of the maxilla studied by the implant method." Scand J Plast Reconstr Surg 8, 26-33.

Björk A, Solow B (1962) "Measurement on radiographs." J Dent Res 41, 672-683.

Braun F (1966) "A Contribution to the problem of bronchial asthma and extension of the palatine suture." Trans Europ Orthod Soc 42, 361-364.

Brin I (ed) (1981) "Rapid maxillary expansion in cats: effect of age on sutural cyclic nucleotides." Amer J Orthod 79, 162-175.

Broca M (1862) "Sur les projections de la tête, et sur un nouveau procédé decephalometric." Bull de la Soc.d'Anthrop. de Paris 3: 514-544.

Brodie A G (1950) "Anatomy and physiology of head and neck musculature." Amer J Orthod 36, 831-844.

Broms P, Jonson B, Lamm C J (1978) "A universal way to evaluate the curve in rhinomanometry." Acta Otolaryngol (Stockh) Suppl June 360, 22-23.

Broms P (1982a) "Rhinomanometry 3. Procedures and criteria for distinction between skeletal stenosis and mucosal swelling." Acta Otolaryngol (Stockh) 94, 361-370.

Broms P, Ivarsson A, Jonson B (1982b) "Rhinomanometry 1. Simple equipment." Acta Otolaryngol (Stockh) 93, 455-460.

Broms P, Jonson B, Lamm C J (1982c) "Rhinomanometry 2. A system for numerical description of nasal airway resistance." Acta Otolaryngol Stockh) 94, 157-68.

Broms P, Jonson B, Malm L (1982d) "Nasal resistance in perennial non-allergic rhinitis. Postural variations and effects of topical application of terbutaline." Rhinology 18, 73-79.

Brown G V I (1903) "The application of orthodontia principles to the prevention of nasal disease." Dental Cosmos 45, 765-775.

Brown G V I (1909) "Surgical and therapeutic aspects of maxillary readjustments, with special reference to nasal stenosis, hare-lip, cleft palate and speech." Dental Cosmos 51, 7-17.

Brown M (1981) "Eight methods of analysing a cephalogram to establish anteroposterior skeletal discrepancy." Br J Orthod 8, 139-146.

Bushey R S (1977) "Posterior crossbite: a four dimensional assessment." Angle Soc.Pap.

Chaconas S J (1969) "A statistical evaluation of nasal growth." Amer J Orthod 56, 403-414.

Cleall J F, Alexander W J, McIntyre H M (1966) "Head posture and its relationship to deglutition." Angle Orthod 36, 335-350.

Cleall J F, Begole E A, Chebib F S (1979) "Craniofacial morphology: a principal component analysis." Amer J Orthod 75, 650-666.

Clement P A R (1984) "Committee report on standardization of rhinomanometry." Rhinology 94, 523-529.

Clements B S (1969) "Nasal imbalances and the orthodontic patient." Amer J Orthod 55, 244-264; 55, 329-352; 55, 477-497.

Cohen A M (1984) "Uncertainty in cephalometrics." Brit J Orthod 11, 144-148.

Cole P, Haight J S (1984) "Mechanisms of nasal obstruction in sleep." Laryngoscope 94, 1557-1559.

Cole S C (1988) "Natural Head position, posture and prognathism." Brit J Orthod 15, 227-239.

Cooke M S (1990) "Five year reproducibility of natural head posture: a longitudinal study." Amer J Orthod 97, 489-94.

Cooke M S, Wei S H Y (1988) "A summary five-factor cephalometric analysis based on natural head posture and the true horizontal." Amer J Orthod 93, 213-223.

Cotton L A (1978) "Slow maxillary expansion - skeletal versus dental response to low magnitude force in Macaca mulatta." Amer J Orthod 73, 1-23.

Courtiss E H, Goldwyn R M (1983) "The effects of nasal surgery on airflow." Plast Reconstr Surg 72, 9-21.

Dahl E (1970) "Craniofacial morphology in congenital cleft lips/palate." Acta Odon Scand 28: suppl 57.

Dahl W, Kreiborg S (1977) "Craniofacial growth and long term treatment planning in congenital craniofacial anomalies." Trans Europ Orthod Soc 53, 179-190.

Daly P, Preston C B, Evans W G (1982) "Postural response of the head to bite opening in adult males." Amer J Orthod 82, 157-160.

Da Silva O G, Boas M C V, Fapelozza L (1991) "Rapid maxillary expansion in the primary and mixed dentitions: a cephalometric evaluation." Amer J Orthod 100, 171-181.

Davida E (1926) "Proportionsuntersuchungen auf Grund des Knochenvolumens und der Volumenders der Extremitatsknochen." Anat. Anz Jena: 61: 128-136.

Debbane E F (1958) "A Cephalometric and histologic study of the effect of orthodontic expansion of the midpalatal suture of the cat." Amer J Orthod 75, 187-219.

Derichsweiler H (1953) "La disjunctions de la suture mediane." Trans Eur Orthod Soc 29: 257.

Devenish E, Foster D, Chinn D (1982) "An improved method of differential rapid maxillary expansion in Cleft Palate." Brit J Orthod 9, 129-131.

Downs W B (1956) "Analysis of the Dentofacial Profile." Angle Orthod 26, 191-212.

Drettner B (1960) "The nasal airway and hearing in patients with cleft palate." Acta Otolaryngol (Stockh) 52, 131-142.

Ekstrom C, Henrikson W (1977) "Mineralization in the midpalatal suture after orthodontic expansion." Amer J Orthod 71, 449-455.

Eriksen E, Solow B (1991) "Linearity of cephalometric digitizers." Euro J Orthod 13, 337-342.

Felli A J, McCall W D (1979) "Jaw muscle silent periods before and after rapid palatal expansion." Amer J Orthod 76, 676-681.

Fever D D (1974) "The value of the PM reference line for estimating natural head position." Angle Orthod 44, 189-193.

Fjellvang H, Solow B (1986) "Craniocervical postural relations and craniofacial morphology in 30 blind subjects." Amer J Orthod 90, 327-334.

Foster T D, Chinn D (1977) "Differential rapid maxillary expansion in cleft palate." Br J Orthod 4, 139-141.

Fotis V, Melsen B, Williams S (1985) "Post-treatment changes of skeletal morphology following treatment aimed at a restriction of maxillary growth." Amer J Orthod 88, 288-296.

Frank S W, Engel G A (1982) "The effects of maxillary quadhelix appliance expansion on cephalometric measurements in growing orthodontic patients." Amer J Orthod 81, 378-389.

Freeman R S (1981) "Adjusting A-N-B angles to reflect the effect of maxillary position." Angle Orthod 51, 162-171.

Fromm B, Lundberg M (1970a) "Postural behaviour of the hyoid bone in normal occlusion and before and after surgical correction of mandibular protrusion." Sven Tandlak Tidskr 63, 425-433.

Glassman A S, Natigian S J, Medway J M, Aronowitz H I (1984) "Conservative surgical orthodontic rapid palatal expansion: sixteen cases." Amer J Orthod 86, 207-213.

Graber T M (1975) "Current Orthodontic Concepts and Techniques." Philadelphia: W B Saunders: 371-375.

Gravely J F, Benzies P M (1974) "The Clinical Significance of tracing error in cephalometry." Br J Orthod 3, 95-101.

Gray L (1982) "The Development of septal and dental deformity from birth." Angle Orthod 52, 265-278.

Gray L (1975) "Results of 310 cases of rapid maxillary expansion selected for medical reasons." J Laryngol-Otol: 89: 601-614.

Greenbaum K, Zachrisson B (1982) "The effect of palatal expansion therapy on the periodontal supporting tissues." Amer J Orthod 81, 12-21.

Greig D G M (1983) "The Reduction of X-Ray Exposure in Dental Practice using Rare-earth Screen/Fast Film Combinations." Br Dent J 155, 17-18.

Grossman W (1963) "Rapid expansion in cleft palate cases." Trans Eur Orthod Soc 39: 366-372.

Gryson J A (1977) "Changes in mandibular interdental distance concurrent with rapid maxillary expansion." Angle Orthod 47, 186-192.

Guenther T A, Sather A H, Kern E B (1984) "The effect of Le Fort I maxillary impaction on nasal airway resistance." Amer J Orthod 85, 308-315.

Gurley W H, Vig P S (1982) "A technique for simultaneous measurement of nasal and oral respiration." Amer J Orthod 82, 33-41.

Guyman G W et al (1980) "Ankylosed teeth as abutments for palatal expansion in the rhesus monkey." Amer J Orthod 77, 486-499.

Haas A J (1961) "Rapid expansion of the maxillary dental arch and nasal cavity by opening the midpalatal suture." Angle Orthod 31, 73-90.

Haas A J (1970) "Palatal Expansion: Just the beginning of dentofacial orthopaedics." Amer J Orthod 57. 219-255.

Haas A J (1980) "The Long-term Post-treatment Evaluation of rapid maxillary expansion." Angle Orthod 50.. 189-217.

Haas A J (1965) "The treatment of Maxillary Deficiency by Opening the Mid Palatal Suture." Angle Orthod 35: 200-217.

Haight J S, Cole P (1983) "The site and function of the nasal valve." Laryngoscope 93, 49-55.

Hald A (1960) "Statistical Theory with Engineering Applications." New York and London, J Wiley & Sons pp 287-289.

Hansen J B, Mansson A, Solow B (1984) "Computerised research equipment for rhinomanometric recording." Abstracts Europ Rhinol Soc 10, 32.

Hartgerink D V, Vig P S, Abbott D W (1987) "The effect of rapid maxillary expansion on nasal airway resistance." Amer J Orthod 92, 381-389.

Hartgerink D V, Vig P S (1989) "Lower anterior facial height and lip incompetence do not predict nasal airway obstruction." Angle Orthod 59: 17-23.

Harvold E P, Vargervik K, Chierici G (1973) "Primate experiments on oral sensation and dental malocclusions." Amer J Orthod 63, 494-508.

Hasegawa M, Kern E B (1977) "The human nasal cycle." Mayo Clin Proc 52, 28-34.

Hasegawa M, Kern E B (1978) "Variations in nasal resistance in man: a rhinomanometric study of the nasal cycle in 50 human subjects." Rhinology 16, 19-29.

Hasegawa M, Kern E B, O'Brien P C (1979) "Dynamic changes of nasal resistance." Ann Otol Rhinol Laryngol 88,: 66-71.

Haskell B, Day M, Tetz J (1986) "Computer-aided modelling in the assessment of the biomechanical determinants of diverse skeletal patterns." Amer J Orthod 89. 363-382.

Hawley C A (1912) "A study of maxillary movement." Items of Interest N Y 30: 426-451.

Heaf D P, Helms P J, Dinwiddie R, Matthew D J (1982) "Nasopharyngeal airways in the Pierre-Robin Syndrome." J Paed: 100 : 698-703.

Hellsing E, McWilliam J, Reigo T, Spangfort E (1987) "The relationship between craniofacial morphology, head posture and spinal curvature in 8, 11 and 15 year old children." Eur J Orthod 9, 254-264.

Henriksen J M, Wenzel A (1984) "Effect of an intranasally administered corticosteroid (budesonide) on nasal obstructions, mouth breathing and asthma." Am Rev Respir Dis 130, 1014-1018.

Hersey H G, Stewart B L, Warren D W (1976) "Changes in nasal airway resistance associated with rapid maxillary expansion." Amer J Orthod 69, 274-284.

Hicks E P (1978) "Slow maxillary expansion: a clinical study of the skeletal versus dental response to low-magnitude force." Amer J Orthod 73. 121-141.

Hinton V, Warren D W (1985) "Airway pressures during breathing in normal and nasally incompetent subjects." Amer J Orthod 88, 358-359.

Holcomb A E, Meredith H V (1956) "Width of the dental arches at the deciduous canines in white children 4 to 8 years of age." Growth 20, 159-177.

Holdaway R A (1956) "Changes in relationship of points A and B during orthodontic treatment." Amer J Orthod 42, 176-193.

Horowitz S L, Thompson R H (1964) "Variations of the craniofacial skeleton in post-adolescent males and females." Angle Orthod 34, 97-102.

Howard R D (1969) "A removable component system for rapid maxillary expansion." Trans Eur Orth Soc, 485-488.

Howe R P (1982) "Palatal expansion using a bonded appliance." Amer J Orthod 82. 464-468.

Howells W W (1957) "The cranial vault: Factors of size and shape." Amer J Phys Anthrop 15, 19-48.

Houston W J B (1982) "A comparison of the reliability of measurement of cephalometric radiographs by tracings and direct digitization." Swed Dent J (Suppl) 15, 99-103.

Houston W J B (1983) "The analysis of errors in orthodontic measurements." Amer J Orthod 83, 382-390.

Huddart A G, Clarke J, Thacker T (1971) "The application of computers to the study of maxillary arch dimensions." Br Dent J 130, 397-404.

Hudgel D W, Robertson D W (1984) "Nasal resistance during wakefulness and sleep in normal man." Acta Otolaryngol (Stockh) 98, 130-135.

Huggare J (1991) "Association between morphology of the first cervical vertebrae, head posture and craniofacial structure." Eur J Orthod 13, 435-440.

Huggare J, Ronning O (1986) "The effect of cold air on head posture." Eur J Orthod 8, 17-20.

Ingelstedt S, Jonson B, Rundcratz H (1969) "A clinical method for determination of nasal airway resistance." Acta Otolaryngol (Stockh) 68, 189-200.

Ingervall B, Thuer U (1988) "Cheek pressure and head posture." Angle Orthod 58, 47-57.

Isaacon R J, Ingram A H (1964a) "Forces produced by rapid maxillary expansion. I: Design of force measuring system." Angle Orthod 34. 261-269.

Isaacson R J, Ingram A H (1964b) "Forces produced by rapid maxillary expansion.II: Forces present during treatment." Angle Orthod 34, 261-270.

Jacobson A (1975) "The "Wits" appraisal of jaw disharmony." Amer J Orthod 67(2), 125-138.

Jacobson A (1976) "Application of the "Wits" appraisal." Amer J Orthod 70, 179-189.

Jacobson R L, Jacobson A (1980) "Point A revisited." Amer J Orthod 77, 92-96.

Jarvinen S (1981) "A comparison of two angular and two linear measurements used to establish sagittal apical base relationship." Eur J Orthod 3, 131-134.

Jarvinen S (1985) "An analysis of the variation of the ANB angle: A statistical appraisal." Amer J Orthod 87,144-126.

Johnson E L (1950) "The Frankfort mandibular plane angle and the facial pattern." Amer J Orthod 36, 516-533.

Jonas I, Mann W, Schlenter W (1982) "Hals-Nasen-Ohren arztliche befunde heim offenen Biss." Fortschr. KieferorttopL 43, 127-138.

Jonson B, Malm L, Ivarsson A, Benthin M, Lamm C J (1983) "Automated rhinomanometry." Rhinology 21, 265-272.

Jonsson G, Thilander B (1979) "Occlusion, arch dimensions and craniofacial morphology after palatal surgery in a group of children with clefts in the secondary palate." Amer J Orthod 76, 243-255.

Kayser R (1895) "Die exacte Messung der Luftdurchgängigkeit der Nast." Arch.Laryng.Rhinol. 3, 101-120.

Kennedy J W III, Bell W H, Kimbrough O L (1976) "Osteotomy as an adjunct to rapid maxillary expansion." Amer J Orthod 70(2), 123-137.

Kern E B (1973) "Rhinomanometry." Otolaryngol Clin North Amer 6, 863-874.

Kern E B (1981) "Committee report on standardization of rhinomanometry." Rhinology 19, 231-236.

Kortekangas A E (1972) "Significance of anterior and posterior technique in rhinomanometry." Acta Otolaryngol (Stockh) 73, 218-221.

Koskenvuo M, Kaprio J, Partinen M (1985) "Snoring as a risk factor for hypertension and angina pectoris." The Lancet Apr 20. pp 893-895.

Kraut R A (1984) "Surgically assisted rapid maxillary expansion by opening the mid-palatal suture." J Oral Maxillofac. Surgery: 42: 651-655.

Krebs A (1964) "Mid-palatal suture expansion studied by the implant method over a 7 year period." Trans Europ Ortho Soc 131-142.

Kudlick V (1973) "Die answertung der amsaurenbehaudlung auf grand von messingerigen der distribution." Z Ernalhrungswiss (suppl) 13; 53-64.

Kylamarkula S, Huggare J (1985) "Head posture and the morphology of the first cervical vertebra." Eur J Orthod 7, 151-156.

Langford S R (1982) "Root resorption extremes resulting from clinical rapid maxillary expansion." Amer J Orthod 81, 371-377.

Langford S R, Sims M r (1982) "Root surface resorption, repair and periodontal attachment following rapid maxillary expansion in man." Amer J Orthod 81, 108-115.

Laptook T (1981) "Conductive hearing loss and rapid maxillary expansion." Amer J Orthod 80, 325-331.

Leiter J C, Baker G L (1989) "The partitioning of ventilation between nose and mouth. The role of nasal resistance." Amer J Orthod 95, 432-438.

Lenz H, Theelen W, Eichler J (1985) "Nasal cycle using rhinomanometric measurements." HNO 33, 58-61.

Liebgott B (1977) "Factors of human skeletal craniofacial morphology." Angle Orthod 47, 222-230.

Linder-Aronson S (1970) "Adenoids. Their effect on mode of breathing and nasal airflow and their relationship to characteristics of the facial skeleton and dentition. A biometric, rhinomanometric and cephalometroradiographic study on children with and without adenoids." Acta Otolaryngol (Stockh) Suppl 265. 100-132.

Linder-Aronson S (1974) "Effects of adenoidectomy on the dentition and nasopharynx." Amer J Orthod 65, 1-15.

Linder-Aronson S (1975) "Effects of adenoidectomy on the dentition and facial skeleton over a period of five years." In: Cook J T (ed) "Transactions of the third International Orthodontic Congress." London, Crosbury Lockwood Staples pp 85-100.

Linder-Aronson S, Backstrom A (1960) "A comparison between mouth and nose breathers with respect to occlusion and facial dimensions." Odont Revy 11, 343-376.

Linder-Aronson S, Lindgren J (1979) "The skeletal and dental effects of rapid maxillary expansion." Br J Orthod 6, 25-29.

Linder-Aronson S, Woodside D, Lunstrom A (1986) "Mandibular growth direction following adenoidectomy." Amer J Orthod 89, 273-284.

Lines P A (1975) "Adult rapid maxillary expansion with corticotomy." Amer J Orthod 67, 44-56.

Loreille J P, Bery J (1981) "Changes in nasal breathing caused by maxillary expansion." Rev. Orthop. Dento.Faciale: 15: 193-208.

Lowe A A, Takada K (1984) "Associations between anterior temporal lobe, and orbicularis oris muscle activity and craniofacial morphology in children." Amer J Orthod 86, 319-330.

Lowe A A, Takada K, Taylor L M (1983) "Muscle activity during function and its correlation with craniofacial morphology in a sample of subjects with Class II Div I malocclusions." Amer J Orthod 84, 204-211.

Lowe A A, Takada K (1986) "Facial morphology and obstructive sleep apnoea." Amer J Orthod. 90: 484-491.

Lundstrom A (1982) "Head posture in relation to the slope of the sella-nasion line." (Reader comment). Angle Orthod 52, 79-83.

McNamara J (1988) "An orthopaedic approach to the treatment of Class III malocclusion in young patients." J Clin Orthod 21: 598-608.

Maguerza O E, Shapiro P A (1980) "Palatal mucoperiostomy; an attempt to reduce relapse after slow maxillary expansion." Amer J Orthod 78: 548-558.

Majouran A,Nanda R (1994) "Biomechanical basis of vertical dimensional control during rapid palatal expansion therapy." Amer J Orthod 106, 322-328.

Maran A G, Walker F S, Rimmer A R, Gibb A G (1971) "A method for the measurement of nasal airway resistance." J Laryngol Otol 85, 803-810.

Marcotte M R (1981) "Head posture and dentofacial proportions." Angle Orthod 51, 208-213.

Marshall R (1980) "A nasal mask for posterior rhinometry of each side of the nose separately." Rhinology 18, 43-45.

Masing H (1974) "Nasal pressure flow studies in adults and children." Rhinology 12; 137-143.

McCracken J G (1970) "Rapid maxillary expansion as an integral part of orthodontic treatment." Brit Soc Study Orthod 75-79.

McWilliam J S, Welander U (1978) "The effect of image quality on identification of cephalometric landmarks" Angle Orthod 48: 49-56.

Melsen B (1972) "A histological study of the influence of sutural morphology and skeletal maturation on rapid palatal expansion in children." Trans Eur Orth Soc 499-506.

Melsen B (1975) "Palatal growth studies on human autopsy material." Amer J Orthod 68: 42-54.

Mesnard L (1929) "Immediate separation of the maxilla as a treatment for nasal impermeability: Dent Record 49: 371-372.

Meredith H V, Ore E, Higley L B (1951) "Relationships between dental arch widths and widths of the face and head." Amer J Orthod 37, 193-204.

Mew J R C (1977) "Semi-rapid maxillary expansion." Br Dent J 143, 301-307.

Mew J R C (1983) "Relapse following Maxillary Expansion ("semi-rapid")." Amer J Orthod 83, 56-61.

Midtgard J, Bjork G, Linder-Aronson S (1974) "Reproducibility of cephalometric landmarks and errors of measurements of cephalometric cranial distances." Angle Orthod 44, 56-61.

Mink P J (1920) "Physiologie der oberen Luftwete." Acta Otolaryngol 42.

Montgomery W M, Vig P S, Staab E V, Matteson S R (1979) "Computed tomography: A three dimensional study of the nasal airway" Amer J Orthod 76: 363-375.

Mondro J F (1977) "An improved direct-bonded palatal expansion appliance." J Clin Orthod. 11: 203-206.

Mossaz G F, Byloff F K, Richter M (1992) "Unilateral and bilateral corticotomies for correction of maxillary transverse discrepancies." Eur J Orthod 14; 110-116.

Moorrees C F A, Kean M R (1958) "Natural head posture: a basic consideration in the interpretation of cephalometric radiographs." Amer J Physic Anthrop 16, 213-234.

Moss M L (1962) "The Functional Matrix." Vistas in Orthodontics 125, 85-98. published Lea and Febiger, Philadelphia.

Moss M L (1964) "Vertical growth of the human face." Amer J Orthod 50, 359-376.

Moss M L, Bromberg B E, Song I C (1968) "The passive role of nasal septal cartilage in mid-facial growth." Plast & Reconstr Surg 41, 536-542.

Moss M, Skalak R, Patel H (1985) "Finite element method modelling of craniofacial growth." Amer J Orthod 87: 453-472.

Mossey P, Sandham J A (1989) "Maxillonasal dysplasia, mandibular retrognathia and cleft palate." Angle Orthod 59, 257-262.

Motte W, Pfister R (1982) "Adenoide-ein kausaber Faktor bein vertikalen Wachstumsmunster?" Foortschr, Kieferorthop. 43: 19-28.

Murphy K E, Preston C B, Evans W G (1991) "The development of instrumentation for the dynamic measurement of changing head posture." Amer J Orthod 99, 520-526.

Mygind N (1980) "Measurement of nasal airway resistance. Is it only for article writers?" (Editorial). Clin Otolaryngol 5, 161-163.

Nakasima A, Ichinose M, Nakata S, Takahama Y (1982) "Heredity factors in the Craniofacial morphology of Angles Class II and Class III malocclusions." Amer J Orthod 82, 150-156.

Nicolson P T, Plint O A (1989) "A long term study of rapid maxillary expansion and bone grafting in cleft lip and palatal patients." Eur J Orthod 11, 186-192.

Odenrick L (1982) "Root surface resorption in two cases of rapid maxillary expansion." Br J Orthod 9, 37-40.

Olow-Nordenram M, Thilander B (1987) "The craniofacial morphology in individuals with maxillonasal dysplasia (Binder's syndrome). A longitudinal cephalometric study of orthodontically untreated children." Eur J Orthod 9, 224-236.

Opedebeek H, Bell W H, Eisenfield J, Mischelvitch D (1978) "The Short Face Syndrome." Amer J Orthod 73, 499-511.

Opedebeek H, Bell W H, Eisenfield J, Mischelvitch D (1978) "Comparative study between the SFS (short face syndrome) and LFS (long face syndrome) rotation as a possible morphogenetic mechanism." Amer J Orthod 74, 509-521.

Owen A H (1983) "Morphologic changes in the transverse dimension using rapid maxillary expansion." Amer J Orthod 83: 200-217.

Pavlin D, Vukicevic B (1984) "Mechanical reactions of the facial skeleton to maxillary expansion determined by laser holography." Amer J Orthod 85: 498-507.

Persson M, Thilander B (1977) "Palatal suture closure in man from 15 to 35 years of age." Amer J Orthod: 72: 42-52.

Phillips C, Snow M D, Turvey T A, Profitt W R (1991) "The effect of orthognathic surgery on head posture." Eur J Orthod 13, 397-403.

Posnick B (1978) "Craniovertical angulation and morphogenic variables in children: A cephalometric study." M.S. Thesis, University of North Carolina.

Principato J J, Wolf P (1985) "Paediatric nasal resistance." Laryngoscope 95, 1067-1069.

Proctor D F (1977) "The Upper Airways 1. Nasal physiology and defense of the lungs." Am Rev Resp Dis 115: 97-129.

Pullen H A (1912) "Expansion of the dental arch and opening of the maxillary suture in relation to the development of the internal and external face." Dental Cosmos 53: 509-528.

Rao S, Potdar A (1981) "Nasal airflow with body in various positions." Rhinology 19, 149-154.

Rasmus R L, Jacobs R M (1969) "Mouth breathing and malocclusion: Quantitative technique for measurement of oral and nasal airflow velocities." Angle Orthod 39: 296-302.

Remmelink H J (1988) "Orientation of Maxillary Sutural Surfaces." Eur J Orthod 10: 223-226.

Richardson A (1966) "An investigation into the reproducibility of some points, planes and lines used in cephalometric analysis." Amer J Orthod 52: 637-651.

Ricketts R M (1957) "Planning treatment on the basis of the facial pattern and an estimate of its growth." Angle Orthod 27, 14-37.

Ricketts R M (1961) "Cephalometric analysis and synthesis." Angle Orthod 13, 141-156.

Ricketts R M (1968) "Esthetics, environment and the law of lip relation." Amer J Orthod 54, 272-289.

Ricketts R M, Bench R W, Hilgers J J, Schulhof R J (1972) "An overview of computerized cephalometrics." Amer J Orthod 61, 1-28.

Riedel R A (1952) "The relation of maxillary structures to cranium in malocclusion and in normal occlusion." Angle Orthod 22, 142-145.

Riolo M L, Moyers R E, McNamara J A, Hunter W S "An atlas of craniofacial growth." Monograph No 2, Craniofacial Growth Series. Ann Arbor, Centre for Human Growth and Development, University of Michigan.

Rohrer F (1925) "Physiologie der Atembewegung." Handbuch der normalen und pathologischen physiologie (ed.Bette) Berlin 2: 70-127.

Ross R B (1965) "Cranial base in children with lip and palate clefts." Cleft Palate Journal 2, 157-166.

Roth R (1982) "The 'Wits' appraisal - its skeletal and dento-alveolar background." Eur J Orthod 4, 21-28.

Saito A, Nishihata S (1981) "Nasal airway resistance in children." Rhinology 19, 149-154.

Sandham J A (1987) "The measurement of craniofacial morphology, head posture and nasal airflow in patients with congenital cleft of lip and palate." Ph.D. Thesis University of Edinburgh.

Sandham J A (1988) "Repeatability of head posture recordings from lateral cephalometric radiographs." Br J Orthod 15, 157-162.

Sandham J A (1988) "Rhinomanometric method error in the assessment of nasal respiratory resistance." Rhinology 2b: 191-201.

Sandham J A, Duvall R (1985) "Natural Head Posture in Cephalometric Radiography." Radiograph 51: 287-288.

Sandham J A and Solow B (1987) "Nasal respiratory resistance in cleft lip and palate." Cleft Palate Journal 24: 278-285.

Sandstrom R A, Klapper L (1988) "Expansion of the lower arch concurrent with rapid maxillary expansion." Amer J Orthod 94, 296-302.

Sarnas K V, Björk A, Rune B (1992) "Long term effect of rapid maxillary expansion studied in one patient with the aid of metallic implants and roentgen stereometry." Eur J Orthod, 427-432.

Sarnas K V, Solow B (1980) "Early adult changes in the skeletal and soft tissue profile." J Europ Orthod Soc 2, 1-12.

Sarven D M, Johnston M W (1989) "Skeletal changes in vertical and anterior displacement of the maxilla with bonded rapid palatal expansion appliances." Amer J Orthod 95: 462-466.

Scheideman G B, Bell W H, Legan H L, Finn R A, Reisch J S (1980) "Cephalometric analysis of dentofacial normals." Amer J Orthod 74, 404-420.

Schultz A H (1942) "Conditions for balancing the head in primates." Amer J Phys Anthropol 29, 483-497.

Schwarz A H (1926) "Kopfhaltung und Keifer." Z Stomatol. 24: 669-744.

Schwarz G, Thrash W (1985) "Tomographic assessment of nasal septal changes following surgical/orthodontic rapid maxillary expansion." Amer J Orthod 87, 39-45.

Showfety K J, Vig P S, Matteson S (1983) "A simple method for taking natural head position cephalograms." Amer J Orthod 83, 495-500.

Siersbaak-Nielsen S, Solow B (1982) "Intra- and inter-examiner variability in head posture recorded by dental auxiliaries." Amer J Orthod 82, 50-57.

Skieller V (1964) "Expansion of the midpalatal suture by removable plates, analysed by the implant method." Trans Eur Orthod Soc 38, 143-158.

Solow B (1966) "The pattern of craniofacial association. A morphological and methodological correlation factor analysis study on young male adults." Acta Odont. Scand. 24 (Suppl) 46, 9-174.

Solow B (1980) "The dentoalveolar compensatory mechanism: background and clinical implications." Br J Orthod 7, 145-161.

Solow B, Barrett M J, Brown T (1982) "Craniocervical morphology and posture in Australian Aboriginals." Amer J Phys Anthr 59, 33-45.

Solow B, Greve E (1979) "Craniocervical angulation and nasal resistance." In: McNamara J A (ed) "Naso-respiratory function and craniofacial growth." Ann Arbor, University of Michigan pp87-119.

Solow B, Greve E (1980) "Rhinomanometric recording in children." Rhinology 18, 31-42.

Solow B, Kreiborg S (1977) "Soft-tissue stretching: a possible control factor in cranio-facial morphogenesis." Scand J Dent Res 85, 505-507.

Solow B, Sandham J A (1991) "Nasal airflow characteristics in a normal sample." Eur J Orthod 13, 1-6.

Solow B, Siersbaak-Nielson S, Greve E 1984) "Airway adequacy, head posture and craniofacial morphology." Amer J Orthod 86, 132-140.

Solow B, Tallgren A (1971a) "Natural head position in standing subjects." Acta Odont Scand 29, 591-607.

Solow B, Tallgren A (1971b) "Postural changes in craniocervical relationships." Tandlaeg 75, 1247-1257.

Solow B, Tallgren A (1975) "Craniocervical posture in relation to skeletal and dentoalveolar morphology." Trans Eur Orthod Soc, 111-115.

Solow B, Tallgren A (1976) "Head posture and craniofacial morphology." Amer J Phys Anthr 44, 417-436.

Solow B, Tallgren A (1977) "Dentoalveolar morphology in relation to craniocervical posture." Angle Orthod 47, 157-164.

Solow B, Tallgren A (1987) "Hyoid Bone position, facial morphology and head posture in adults." Eur J Orthod 9, 1-8.

Soresen H, Solow B, Greve E (1989) "Assessment of the nasopharyngeal airway. A Rhinomanometric and Radiographic Study in Children with Adenoids." Acta Otolaryngol (Stockh) 89, 227-232.

Sosa F A, Graber T M, Muller T P (1982) "Postpharyngeal lymphoid tissue in Angle Class I and Class II malocclusions." Amer J Orthod 81: 299-309.

Spolyar J (1984) "The design, fabrication and use of a full coverage bonded rapid maxillary expansion appliance." Amer J Orthod 86, 136-145.

Stoksted P (1951) "Rhinomanometric examinations of schoolchildren with adenoid vegetations." Acta Otolaryngol (Stockh) 39, 44-45.

Stoksted P (1959) "Rhinomanometri. Diagnostik njaelpemiddel ved rhinologiske lidelser." Ugerskr Laeger 121, 1181-1190.

Strohl K P, O'Cain C F , Slutsky A S (1982) "Alae nasi activation and nasal resistance in healthy subjects." J Appl Physio 52, 1432-1437.

Subtelny J D (1959) "A longitudinal study of soft tissue facial structures and their profile characteristics, defined in relation to underlying skeletal structures." Amer J Orthod 47, 481-507.

Subtelny J D (1961) "The soft tissue profile, growth and treatment changes." Angle Orthod 31, 105-122.

Tallgren A, Solow B (1981) "Longterm changes in hyoid position and craniocervical posture in complete denture wearers." J Dent Res 60, 473-479.

Tallgren A, Solow B (1987) "Hyoid bone position, facial morphology and head posture in adults." Eur J Orthod 9, 1-8.

Ten Cate A R, Freeman E, Dickenson J B (1977) "Sutural development and its response to rapid expansion." Amer J Orthod 71: 622-636.

Thompson R W (1974) "Extraoral high-pull forces with rapid palatal expansion in the Macaca mulatta." Amer J Orthod 66, 302-317.

Timms D J (1974) "Some medical aspects of rapid maxillary expansion." Br J Orthod 1, 127-132.

Timms D J (1976) "Long term follow up of cases treated by rapid maxillary expansion." Trans Eur Orthod Soc: 211-215.

Timms D J (1980) "A study of basal movements with rapid maxillary expansion." Amer J Orthod 77, 500-507.

Timms D J (1986) "The effect of rapid maxillary expansion on nasal airway resistance." Br J Orthod 13, 221-228.

Timms DJ (1990) "Rapid maxillary expansion in the treatment of nocturnal enuresis." Angle Orthod 60, 229-234.

Timms D J, Moss J P (1971) "An histological investigation into the effects of rapid maxillary expansion on the teeth and surrounding tissues." Trans Eur Orthod Soc 263-272.

Timms D J, Preston C B, Daly P F (1982) "A computed tomographic assessment of maxillary movement induced by rapid maxillary expansion - a pilot study." Eur J Orthod 4, 123-127.

Trenouth M J, Davies P H J, Johnson J S (1985) "A statistical comparison of three sets of normative data from which to derive standards for craniofacial measurement." Eur J Orthod 7, 193-200.

Turbyfill W J (1976) "The long-term effect of rapid maxillary expansion." Masters Thesis, University of North Carolina, Chapel Hill.

Turvey T A, Hall D J, Warren D W (1984) "Alterations in nasal airway resistance following superior repositioning of the maxilla." Amer J Orthod 85, 109-114.

Ung N, Koenig J, Shapiro P A, Trask G (1990) "A quantitative assessment of respiratory patterns and their effects on dentofacial developments. " Amer J Orthod 98, 523-532.

Van Dishoek H (1942) "Inspiratory Nasal Resistance." Acta Otolaryngol (Stockh) 30: 431-439.

Vig P S, Rink J F, Showfety K J (1983) "Adaption of head posture in response to relocating the centre of mass: a pilot study." Amer J Orthod 83, 138-142.

Vig P S, Showfety K J, Phillips C (1980) "Experimental manipulation of head posture." Amer J Orthod 77, 258-268.

Von Baer K E, Wagner B (1861) "Bericht über die Zusammen kunft eiriger Anthropologen im September 1861 in Göttingen zum Zweeke gemeinsamer Besprechrungen." Leopold Voss, Leipzig.

Walker G F (1972) "A new approach to the analysis of craniofacial morphology and growth." Amer J Orthod 61, 221-230.

Walpole-Day A J, Foster D (1970) "The measurement of variations in intra-oral air pressure." Angle Orthod 40, 45-50.

Warren D W, Hershey H, Turvey T, Hinton B, Hairfield W (1987) "The Nasal Airway following Maxillary Expansion." Amer J Orthod 91, 111-116.

Warren D W, Duany L F, Fischer N D (1969) "Nasal pathway resistance in cleft lip and palate subjects." Cleft Palate J 6, 134-140.

Warren D W, Hairfield W, Seaton D (1987) "The relationship between nasal airway cross-sectional area and nasal resistance." Amer J Orthod 92, 390-395.

Warren D W, Hairfield W M, Dalston E M (1990) "The effect of age on nasal cross-sectional area and respiratory mode in children." Laryngoscope 100, 89-93.

Watson M L, Warren D W, Fischer N D (1968) "Nasal resistance, skeletal classification and mouth breathing in orthodontic patients." Amer J Orthod 54, 367-379.

Weber I J, Preston C B, Wright P G (1981) "Resistance to nasal airflow related to changes in head posture." Amer J Orthod 80, 536-545.

Wemmer D (1985) "A cephalometric evaluation of simultaneous face mask/rapid maxillary expansion in the mixed dentition." Amer J Orthod 87. 87

Wenzel A, Henrikson J, Melsen B (1983) "Nasal respiratory resistance and head posture: effect of intranasal corticosteroid (budesonide) in children with asthma and perennial rhinitis." Amer J Orthod 84, 422-426.

Wenzel A, Hojensgaard E, Henriksen J M (1985) "Craniofacial morphology and head posture in children with asthma and perennial rhinitis. Eur J Orthod 7, 83-92.

Wenzel A, Williams S, Ritzau M (1989a) "Changes in head posture and nasopharyngeal airway following surgical correction of mandibular prognathism." Eur J Orthod 11, 37-42.

Wenzel A, Williams S, Ritzau M (1989b) "Relationship of changes in craniofacial morphology, head posture and nasopharyngeal airway size following mandibular osteotomy." Amer J Orthod 96, 138-143.

Wertz R A (1968) "Changes in nasal airflow incident to rapid maxillary expansion." Angle Orthod 38, 1-11.

Wertz R A (1970) "Skeletal and dental changes accompanying rapid midpalatal suture opening." Amer J Orthod 58. 41-66.

Wertz R A and Dreskin M (1977) "Midpalatal suture opening. A normative study." Amer J Orthod 71: 367-381.

Williams H L (1970) "Report of committee on standardization of definitions, terms, symbols in rhinometry of the American Academy of Ophthalmology and Otolaryngology." Rochester, Minnesota.

Williams S, Leighton B C, Nielson J H (1985) "Linear evaluation of the development of sagittal jaw relationship." Amer J Orthod 88, 235-241.

Wisth P J (1972) "Changes of the soft tissue profile during growth." Trans Eur Orthod Soc, pp123-131.

White B C, Woodside D G (1989) "The effect of rapid maxillary expansion on nasal airway resistance." J Otolaryngol 18: 137-143.

Woodside D G, Linder-Aronson S (1979) "The channelization of upper and lower anterior face heights compared to population standard in males between ages 6 to 20 years." Eur J Orthod 32, 57-67.

Wylie W L (1946) "The relationship between Ramus height, dental height and overbite." Amer J Orthod 32, 57-67.

Wylie W L, Elsasser W A (1948) "Undistorted vertical projections of the head from lateral and postero-anterior roentgenograms." Amer J of Roentgenol 60, 414-417.

Yen P K-J (1960) "Identification of landmarks in cephalometric radiographs." Angle Orthod 30, 35-41.

Zamring J F, Isaacson R J (1965) "Forces produced by rapid maxillary expansion." Angle Orthod 35, 178-186.

Zook E G, Salmond J H (1977) "Anomalies of the cervical spine in cleft palate patients." Plast Reconstr Surg 60, 96-99.

Zwaardemaker H (1889) "An olfactometer." Brit Med J London,(ii), 1295.